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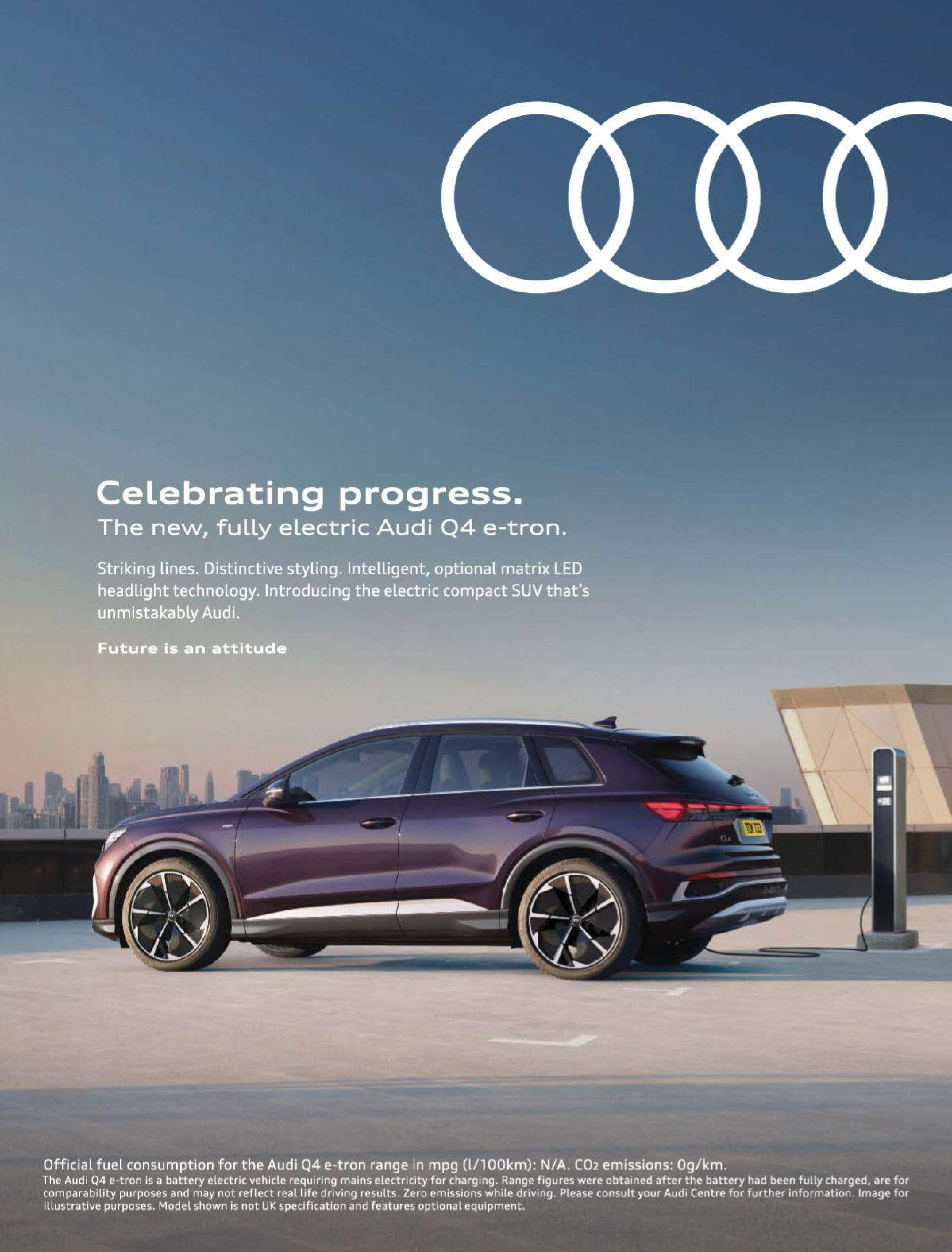

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A new science of consciousness

Most people view themselves as apart from the rest of nature, but a new way of thinking encourages the opposite. In this talk, neuroscientist Anil Seth draws on his original research and collaborations to put forward an exhilarating new idea about how we experience the world and the self. Join us from 6pm BST on 9 September or watch on demand. Tickets available now.

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Great apes Puzzle-solving gorillas shed light on how speech evolved

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Video

Puzzle-solving apes

A project testing great apes' puzzle-solving abilities could offer insight into the mental abilities underpinning language. Researcher Gillian Forrester tells *New Scientist* how this pioneering work could help us spot earlier signs of language disorders in children.

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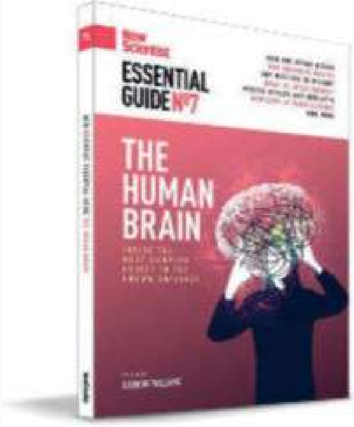
Newsletter

> **"Even the most dry-tolerant microbe on Earth wouldn't stand a chance on Venus"**



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Solving the chemicals crisis

Human ingenuity and innovation caused this emergency – and they can solve it

WHEN the US chemicals company DuPont adopted the slogan "Better Things for Better Living… Through Chemistry" in 1935, it was to try to win over a public wary of new synthetic materials such as nylon, neoprene and pesticides. It seems to have succeeded. For most people, life today is steeped in synthetic chemicals.

Many of these chemicals are benign and do indeed make life better, delivering superior medicines, higher agricultural yields, innovative materials, cleaner water, magical electronic products and a radical abundance of consumer goods.

But better living through chemistry has turned out to be a Faustian pact. Over the past century, tens of thousands of chemicals have been released into the wild with barely a thought for the effects on human health and the environment.

As a problem, this is hardly news, but we are only just getting to grips with its monumental scale. Earlier this year, the United Nations declared waste and pollution to be the third great planetary crisis alongside climate change and biodiversity loss (see page 36).

"We're only just getting to grips with the monumental scale of the chemicals crisis"

In truth, all three are facets of a crisis with the same underlying cause: excessive consumption fed by a linear economic system, which extracts resources, creates useful things (and plenty of useless ones too) and discards the waste products.

Human ingenuity and innovation caused this crisis – but its solutions lie there too. Enlightened industrial chemists and the companies they work for are looking to atone for past actions, developing cleaner, more sustainable products, and working to recognise and remediate the worst effects.

But the pace of change, especially in legislation, is too slow, and greenwash still too prevalent. Leading chemists are now calling for the establishment of a body similar to the Intergovernmental Panel on Climate Change to coordinate and disseminate research on the extent and effects of chemical pollution. That is to be welcomed as a first step towards meaningful international action.

We don't need to retreat into a world without synthetic chemicals. We still need better living – but this time it must be through better chemistry. ▮

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Up, up and over
3D-printed steel bridge opens in Amsterdam **p18**

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Pegasus spyware can allow users to snoop on people's phones

Technology

Spyware scandal

With new revelations on how our phones are being hacked, can Silicon Valley do anything to stop it, asks **Matthew Sparkes**

SPYWARE sold for use in antiterror investigations is being misused to watch journalists, academics and politicians across the world, according to a report by *The Guardian* and others.

NSO Group, based in Israel, is thought to have sold the spyware to countries including Azerbaijan, Bahrain, Saudi Arabia, India and the United Arab Emirates. It allows a user to read data from smartphones and spy via their microphones and cameras. The software, called Pegasus, uses vulnerabilities in smartphone and social media source code.

Technology firms that make these phones and social media platforms are now embroiled in a long-running legal battle with NSO to prevent this hacking.

WhatsApp and Facebook, its parent company, first filed a lawsuit in California in 2019 alleging that NSO had hacked into its servers to infect 1400 phones belonging to WhatsApp users. NSO said that it should have "sovereign immunity" because it sells to non-US governments, an argument that was dismissed in December 2020 and that the firm is appealing. WhatsApp now wants a permanent injunction stopping NSO from attempting to gain access to its systems. The success of the case rests on whether NSO is considered to be hacking into systems or if that is being done by the users of its software.

Other Silicon Valley firms have also joined the case, which is making fresh headlines following an investigation by *The Guardian* and non-profit organisation Forbidden Stories. It claims to have a leaked list of 50,000 phone numbers based across 45 countries that were selected for surveillance by Pegasus's many users, showing that the tool is being used to monitor journalists, political opponents and campaigners as well as being used for antiterror or serious crime investigations.

> **"Litigation may be the most immediate way to rein in the poorly regulated global spyware marketplace"**

Ron Deibert at the University of Toronto in Canada leads a research group that investigates the use of surveillance software such as Pegasus. He says that if his small team can uncover details about how NSO customers are using the tool, the company can as well.

"Litigation may be one of the most immediate ways to rein in the excesses of the poorly regulated global spyware marketplace," says Deibert. "Should litigation succeed and bring real financial penalties to companies like NSO, then the industry as a whole may be incentivised to better control to whom they are selling and how it is being deployed."

Alan Woodward at the University of Surrey, UK, says there is vast profit to be made in finding new ways to exploit software weaknesses, packaging them up and selling them as widely as possible. Unfortunately, once the software is in the hands of a state, it can be targeted at anyone with little oversight.

Stopping the practice may require legislation, but Deibert says this will prove problematic because many states have a vested interest in allowing the hacking to continue, adding that it is an "epidemic of global proportions".

NSO says that it licenses its products to governments "for the sole purpose of preventing and investigating terror and serious crime". NSO denied that its products were being misused, but confirmed that the company would investigate all credible claims of misuse and take appropriate action, such as shutting down access to Pegasus by a state customer – something that it has done "multiple times" in the past. It also denied that the leaked list of phone numbers was a list of targets. The company declined to respond to further questions. ■

Coronavirus

How do we live with covid-19?

The UK government has said it is now time to "learn to live with covid". Here's what that looks like, write **Graham Lawton**, **Michael Le Page**, **Adam Vaughan** and **Clare Wilson**

WITH more than half of adults in the UK having received two doses of vaccine against covid-19, the UK government has decided that the time has come to lift most restrictions in England and get on with life alongside the virus. Since 19 July, people in England have been free to meet up with whoever they want, wherever and whenever they like, for the first time since November 2020, and nightclubs have reopened for the first time since March 2020. Masks and social distancing are largely no longer mandated.

But it won't quite be business as usual, with a predicted spike in cases reaching 100,000 per day in mid-August. So what does it mean to "live with covid" once restrictions have lifted, and what insights can we glean for those living elsewhere too?

What will 100,000 cases a day mean?

The largest spike in recorded cases in the UK so far was in January 2021, which reached around 60,000 a day. But the current wave is different to those that came before. Thanks to vaccines protecting those most at risk, and because the virus is now spreading more among younger people, the link between cases and hospital admissions and deaths has been weakened – but not broken.

Overall, UK government advisers say there is now a fourfold lower chance of hospitalisation and roughly tenfold lower chance of death, compared with the UK's second wave of covid-19, which started in August 2020.

The earliest the next wave might peak is predicted to be mid-August, although the timing hinges on how fast behaviour flips back to pre-pandemic ways, including how many close contacts people make each day, whether face masks are worn in crowded places and how many people work from home.

"I don't think I can be a safe member of society when we have 100,000 cases a day"

A central case modelled for the Scientific Advisory Group for Emergencies (SAGE), which advises the UK government, suggests there would be 100 to 200 deaths and 1000 to 2000 hospitalisations daily at the peak.

However, there is a lot of uncertainty over the figures, because the models are sensitive to small changes in the number of unvaccinated people, the efficacy of vaccines against the delta variant and more. This variation will determine whether hospitals become overwhelmed. In the worst case, deaths and hospital admissions could exceed the peaks seen in spring 2020.

One small positive is people are spending less time in hospital than in past waves, because most are younger. However, Kit Yates at the University of Bath, UK, points out that any increase in hospitalisations will hamper routine treatment, adding to the backlog that has built up during the pandemic. "Certainly, with 100,000 cases, we are going to see pressure on the NHS and routine care being cancelled," he says.

Beyond hospitalisations and deaths, SAGE sees three main risks from a high number of infections: a rise in long covid cases, disruption due to workplace absences and new variants emerging. High prevalence and incidence also makes contact tracing harder.

A waiter in central London, before restrictions were lifted

The overall impact of a third wave may eventually force governments to reimpose some restrictions, says Mark Woolhouse at the University of Edinburgh, UK. "I think it's unlikely. But they do have to prepare for it and plan for it," he says.

Will life feel normal for some people?

There will be some elements of normality for people who are younger, have no underlying health conditions and are fully vaccinated.

However, even if people know they are relatively low risk, they may still be concerned about the possibility of passing the virus on to those who are more vulnerable, given vaccines aren't a guarantee against transmission.

"I'm at low risk, I've had two doses of Pfizer," says Christina Pagel at University College London. "I'm not worried about catching it for me, but I'm very worried about passing it on. Both my parents are extremely clinically vulnerable. I want to see them and I'm not going to do that as freely with these high cases. I don't think I can be a safe member of society when we have 100,000 cases a day."

High cases and the lifting of restrictions may make a large number of people anxious too, says Elise Paul, also at UCL. In June, the percentage of people worried about catching and becoming seriously ill from covid-19 was at

DANIEL LEAL-OLIVAS/AFP VIA GETTY IMAGES

its lowest levels since the start of the pandemic, according to an ongoing survey that she runs. That is expected to rise. "I don't think we are going to see a sudden return to normalcy," says Paul.

What about vulnerable groups?

Those most at risk of getting severely ill from covid-19 include older people, especially those living in care homes, and younger adults with medical conditions such as cancer or a weak immune system. Many of them have been told to "shield" or stay at home when cases have been high.

All such groups in the UK will by now have been offered two vaccine doses, but some will still catch the virus. With outbreaks being seen again in care homes, staff are learning to recognise the different covid-19 symptoms in older people who are vaccinated, says Adam Gordon at the University of Nottingham, UK. Rather than respiratory symptoms and fever, vaccinated residents may become withdrawn, delirious and stop eating and drinking, says Gordon. "The jury's still out on the extent of harm that these less severe infections can cause."

Rising numbers of covid-19 cases, coupled with less social distancing and mask-wearing in public spaces, makes it riskier for vulnerable people to mix with others. The UK government has advised those who are extremely vulnerable that they may wish to take extra precautions, such as only meeting people outside and avoiding those who haven't been fully vaccinated.

A recent study of more than 7 million people in England found that most of those with long-term health conditions, such as asthma and heart disease, got the same level of vaccine protection and antibody response as the general public. But it also found that people with weak immune systems were less protected, with vaccine effectiveness of 74 per cent, compared with about 85 per cent in the general population. And it is likely to be lower in people with the severest immune deficiencies, says Herb Sewell at the University of Nottingham.

Some people with very weak immune systems can even have no antibodies to the coronavirus after two vaccine doses. One such person is Lizi Jackson-Barrett of Romford in the UK, who has a genetic immune deficiency. "There's a real misconception that vulnerable people are all safe," says Jackson-Barrett. "There are huge numbers of us who effectively remain unvaccinated."

What will winters look like?

Winter usually means outbreaks of respiratory viruses including influenza, respiratory syncytial virus (RSV) and those that cause common colds. They barely touched us last winter, suppressed by measures to limit the spread of covid-19. But what about after restrictions are lifted?

Making global predictions is almost impossible, says Azra Ghani at Imperial College London. "Every country is almost unique," she says. But the UK at least can probably expect a worse-than-usual flu season, according to a new report from the Academy of Medical Sciences.

> **"There is some evidence that infection with other viruses can make covid-19 symptoms a lot worse"**

There are still multiple unknowns, including how bad this winter's flu strain will be, how effective the flu vaccine is and how much natural immunity has waned. But the UK can expect 1.5 to 2.2 times the normal number of flu cases, says Ghani, a member of the report's expert advisory group. Flu normally kills 10,000 to 30,000 people a year in England.

RSV is also expected to be up to twice as prevalent than it is in a normal year, which sees 20,000 children under 5 admitted to hospital. The vast majority recover.

There is also the added risk of co-infection, which is when an individual is infected with two or more viruses at the same time, including the SARS-CoV-2 virus that causes covid-19. "Co-infection is quite common in the winter months – some people can harbour three at the same time – and there is evidence that RSV can make covid-19 symptoms quite a lot worse," says Stephen Holgate at the University of Southampton, UK, the report's chair.

This all points to a bleak midwinter in England. "The NHS is already under pressure, so is likely not to be able to cope with these challenges," he says.

How many deaths are acceptable?

Opening up society will mean that more people will die from covid-19 than if restrictions remained. No country has explicitly said the level of covid-19 deaths it will tolerate, but some countries, such as New Zealand, have effectively decided to accept no infections or deaths, instead pursuing an elimination strategy.

Ministers have acknowledged that the ending of all covid-19 restrictions in England will lead to more deaths, but haven't said how many are acceptable.

Modelling by Anne Cori at Imperial College London and her colleagues suggests there could be anything from 9400 to 113,000 deaths from covid-19 in England between 2 July 2021 and 1 June 2022, depending on how people behave and how well the vaccines work, but she stresses the uncertainties. "I would not emphasise any specific numbers," says Cori.

Other modellers agree. "Forecasting death numbers is much more difficult than anything else," says Matt Keeling at the University of Warwick, UK.

Even countries that have pursued an elimination strategy may be forced to tolerate waves of infections and deaths when they open up after vaccination campaigns are complete. ›

Will there be an epidemic of long covid?

As covid-19 is allowed to spread freely, many more people will end up with long covid. Just how many is impossible to predict, however.

There are widely differing estimates of how many infected people get long covid. When Nina Langeland at the University of Bergen and her colleagues followed 250 or so people in Norway who tested positive for covid-19 but didn't need to go to hospital, the team found half of those aged between 16 and 30 years still had symptoms six months later, ranging from loss of taste and smell to fatigue and memory problems.

"I do see our findings as a good reason to immunise teenagers," says Langeland, "to avoid long-term symptoms, which could affect education and studying."

"Long covid is a good reason to immunise teenagers – it could affect education and studying"

By contrast, Tim Spector at King's College London and his colleagues estimate that just 1 in 100 people aged around 20 have long covid after three months. Much of the reason for these differences is due to how long covid is defined, says Spector, with some studies counting any lasting symptom, however minor.

"We've redefined it to say it's a symptom that persists for more than 12 weeks that interferes with your normal functioning or activities," he says. His team estimates that 180,000 people in the UK have or have had long covid according to this definition, and this number is currently growing by 700 each day.

What is clear from his research is that vaccination greatly reduces the risk of getting long covid. "It's maybe a twentieth of what it would have been," says Spector. This is mostly because vaccination reduces the risk of being infected in the first place, but his team's findings suggest that the risk is also halved in those who get infected despite being vaccinated.

What will life be like for children?

England's new covid-19 strategy will mean big changes in schools for most under-18s. The approach this year was to manage children in small groups and avoid them mixing. This bubble system will no longer apply from September, meaning children's social and school lives will be much less constrained.

Schools in England are also dropping face coverings – although they may make temporary returns if there is a school outbreak, the UK government has said.

The new approach is striking because most under-18s in the UK haven't yet been vaccinated and so their infection rate is soaring. This also puts others at risk, Russell Viner, former president of the Royal College of Paediatrics and Child Health, told a Royal Society of Medicine conference earlier this month.

"When children and young people will be the only substantial part of the population that are not vaccinated, we will make true what has been claimed all through the pandemic – children and young people become the source of most infections to vulnerable adults," said Viner.

ANTHONY HARVEY/SHUTTERSTOCK

Students will no longer need to wear face masks in England

What new tech can we expect?

In the 1800s, a growing realisation that poor sanitation was a public health risk led to cities around the world building clean water supplies and sewers. There are now calls for a similar revolution in indoor air quality. "We should have virus-free air indoors," says Lidia Morawska at the Queensland University of Technology in Brisbane, Australia.

She and 40 other researchers from around the world recently called on the World Health Organization to strengthen indoor air quality standards to account for airborne pathogens such as SARS-CoV-2.

According to Morawska, indoor ventilation standards currently focus on temperature, humidity, CO_2 levels and odour. Morawska and others think they should be upgraded to include higher airflow, filtration and disinfection, and that measures of air quality are made publicly available.

One relatively straightforward way to do the latter is through levels of CO_2. "It's a kind of proxy measure for the amount of air that's being shared," says Trisha Greenhalgh at the University of Oxford. Belgium's coronavirus commissioner recently recommended such read-outs for all indoor public spaces and ordered hotels, restaurants, bars and gyms to do so.

Some places are mandating higher standards. In New York City, for example, classrooms must have at least two functioning methods of ventilation, and schools' ventilation status is openly published on a website.

Various groups are working on warning sensors that detect the virus itself in air and dust. Sensors could be embedded in face masks and clothing and made into wearable virus monitors. UV light is also being investigated as a method of disinfecting the air.

Personal technology can help, too. "We're doing a lot with wearables," says Mike Snyder at Stanford University in California. Data from smartwatches can detect warning signs of covid-19 three to four days before symptoms start. "We can tell when you're getting ill because your heart rate jumps up," he says.

What about new treatments?

People who are sick enough to be in hospital may already receive medicines, such as the steroid dexamethasone, and an artificial antibody, tocilizumab, both of which dampen the unhelpful overreaction to the virus by the immune system. But the search is on for treatments that people with milder illness could use at home.

Any drug that works as a treatment could also make a preventative medicine, says Philip Bath at the University of

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Nottingham. Preventative drugs could be taken by vulnerable people who have been in contact with known cases, or if infection rates surge locally. Bath is about to start a trial of two possible preventatives in care homes.

Other trials have already started. Antiviral drugs work by blocking the virus's life cycle. In April, the UK set up an Antivirals Taskforce that aims to have at least two such medicines ready for home use by the end of this year. This month, one leading contender, called molnupiravir, was found to reduce hospital admissions in people with mild covid-19 in India.

80%

Reduction in infections in intensive care staff using novel nasal spray

Some medicines used to treat other illnesses have been rushed into covid-19 trials. Several are being investigated that raise nitric oxide levels, which dilates the airways and blood vessels to make breathing easier. In a different approach, a compound from seaweed which is sprayed up the nose works by coating the nasal passages to block virus entry. A trial in Argentina found it cut the number of intensive care staff who caught the virus by 80 per cent.

More innovative approaches are at an earlier stage of development. One is tiny fragments of antibodies that can be inhaled, called nanobodies. These "decoy particles" are covered with ACE2, the molecule on human cells the virus normally binds to.

Will we live in fear of dangerous variants?

Yes, is the short answer. As long as SARS-CoV-2 continues to circulate in people or animals anywhere in the world, new – and old – variants will remain a threat.

The further evolution of the virus depends on how many chances it has to mutate and what selective pressures are on it. In the UK, with high case numbers and high vaccination levels, conditions are ideal for variants to emerge that are even better at evading vaccine protection.

"The likelihood of this happening is unknown, but such a variant would present a significant risk both in the UK and internationally," SAGE has warned.

This risk has led to criticism of England's approach from other countries. However, with case numbers and vaccination levels rising in many countries, new escape variants – that can at least partially evade vaccines or natural immunity – could emerge just about anywhere. In fact, they are.

In addition to the four "variants of concern" – alpha, beta, gamma and delta – the World Health Organization has already named four "variants of interest" – eta, iota, kappa and lambda – and is monitoring many more emerging variants. It remains to be seen if any are more dangerous than delta.

Clubs in England are now open for the first time since March 2020

REUTERS/CARL RECINE

However, it is unlikely that any new variant will completely dodge the immune protection from vaccines or previous infections, so hospitalisation and death rates should be lower in future waves caused by new variants, as the UK is seeing with delta.

The threat from variants isn't going away anytime soon. In a few decades, younger people might have no immunity to the original SARS-CoV-2 variants. If these lurk in an animal reservoir and get reintroduced into people, they could trigger yet another wave of infections. This is thought to be why younger people were harder hit in the 2009 swine flu pandemic.

What's the endgame?

The covid-19 pandemic will one day be history, but the virus that caused it will not. Just as the 1918 influenza virus is still with us, we will have to learn to live with SARS-CoV-2 and its descendants, says Neil Ferguson at Imperial College London. But what form that relationship will take is unknown.

According to Amalio Telenti at Scripps Research Institute in La Jolla, California, we are currently in a transition period as vaccines wrestle the pandemic under control. After this, he says, we won't eliminate the virus, but it will become endemic, meaning it is a constant presence that ebbs and flows over years or decades.

Once this happens, broadly speaking there are three scenarios, he says. The worst case is a future with waves of severe disease like the deadly flu outbreaks of 1928-29 and 1934-36, both of which were caused by descendants of the 1918-19 flu virus. This scenario could occur if global vaccination rates remain too low, immunity doesn't persist or the virus mutates so it can evade the immune response or becomes more virulent.

The second and most likely scenario, he says, is that SARS-CoV-2 turns into a seasonal virus like flu. But that would still mean intermittent epidemic peaks, as with flu.

The best-case scenario is that the virus fades to become just another seasonal coronavirus like the four that cause the common cold.

Ferguson agrees that the middle scenario is more likely, with low levels of infection and flare-ups where levels of immunity decline. "It will become a classic endemic respiratory disease which we manage, probably through vaccination," he says.

But that wouldn't entail any return to pandemic restrictions, says Graham Medley at the London School of Hygiene & Tropical Medicine. "We don't put special measures in to deal with the flu and in the same way I don't think we'll have special measures in to deal with the coronavirus." ▮

Genetics

‘Borg’ DNA assimilates genes

Stretches of DNA found in microbes steal genetic information from other organisms

Claire Ainsworth

A STRANGE new genetic entity has been discovered in methane-eating microbes, and it could help fill a gap in our understanding of Earth’s climate.

Named “Borgs” after *Star Trek* aliens that assimilate the biology of other creatures, these enigmatic stretches of DNA inhabit single-celled organisms called archaea, where they appear to acquire and swap genes and potentially boost their hosts’ ability to consume methane, one of the most potent greenhouse gases.

“These Borgs seemingly represent a new type of genetic element,” says Thijs Ettema at Wageningen University & Research in the Netherlands, who wasn’t involved in the study.

Scientists have long known about mobile genetic elements, pieces of genetic material that can either move around a host’s genome or sit alongside it and travel between cells. They include plasmids – circular bits of DNA that microbes often swap with each other – and phages, viruses that infect bacteria and archaea.

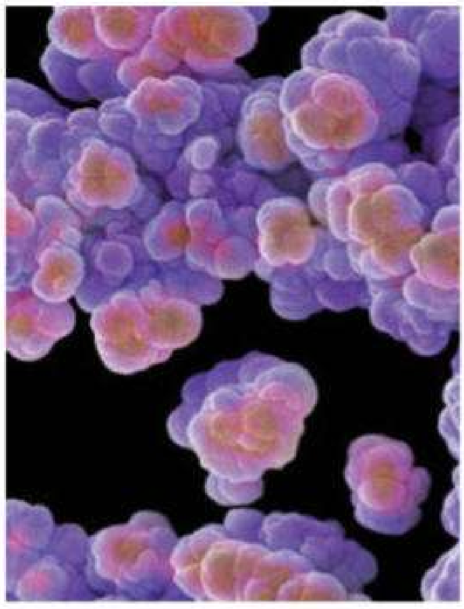
Jill Banfield at the University of California, Berkeley, and her colleagues were using DNA sequencing to study microbial communities living in oxygen-free mud when they stumbled across some unusual stretches of DNA. The team painstakingly stitched these together and reconstructed the full sequences of four Borg elements, naming them Purple, Black, Sky and Lilac. Studies of other samples revealed the existence of a further 15 types.

“The thing that strikes you first is, they’re huge. I mean really huge,” says Banfield. At up to about 1 million DNA letters long – a third the size of their host’s genome – they are the largest mobile genetic elements yet found in archaea or bacteria (bioRxiv, doi.org/gnsb).

Their structure is strange too: for example, unlike circular plasmids, Borg DNA is linear and contains many sections of repeated sequences. None of the proteins coded in the Borg genomes look like those seen in plasmids or viruses, nor do the DNA replications start in the usual sites seen in known plasmids. All in all, they look like something completely new. Some Borgs use CRISPR gene-editing as a kind of microbial immune system, possibly aimed at attacking rival mobile genetic elements in the host. Similar features crop up in other genomes, but have never been seen together like this before.

The large number of protein-coding genes that Borgs contain is also remarkable. While the majority of these are unknown, about a fifth resemble genes found in archaea – particularly those of a methane-consuming genus called *Methanoperedens* in which the Borgs replicate. As well as assimilating host genes, there are signs that different kinds of Borg can swap DNA with each other and move between hosts, potentially allowing *Methanoperedens* to acquire new genes.

A coloured scanning electron micrograph of microbes known as archaea



POWER AND SYRED/SCIENCE PHOTO LIBRARY

Borgs, particularly the Lilac Borg, contain genes that could turbocharge the ability of *Methanoperedens* to consume methane. The balance between methane production and microbial methane consumption directly affects climate, says Sarah Bagby at Case Western Reserve University in Cleveland, Ohio. So scientists want to understand what affects the amount of methane these microbes can consume and how that may change over time.

Borgs may be a missing piece in this puzzle, but right now there is still a lot to learn. Banfield is planning experiments to explore the origin and function of Borg proteins. ▮

Animals

How Galapagos giant tortoises avoid cancer

GALAPAGOS giant tortoises are long-lived in part because their cells are surprisingly sensitive to certain forms of stress. As well as informing research into human medicine, the finding reveals how animals have evolved different ways to resist cancer and ageing.

We would expect large animals to be more susceptible to cancer because they have more cells, each of which has a chance to become cancerous. But recent studies have shown how big, long-lived animals such as elephants have paradoxically low cancer rates thanks to having extra copies of genes involved in suppressing tumour development.

These studies have mostly been done in mammals, raising the question of what similar adaptations other animals might have evolved. So Vincent Lynch at the University at Buffalo, New York, and his colleagues turned to turtles, which come in a large range of body sizes, have lower rates of cancer and can show remarkable longevity. Galapagos giant tortoises, for example, can live for more than 150 years.

They found that Galapagos giant tortoises have evolved a marked reduction in cancer risk, and that their genomes contain extra copies of genes involved in responding to cellular stress caused by damaged or misshaped proteins. The accumulation of such proteins in cells has been associated with ageing and cancer.

“We thought that they might be super resistant to the kinds of stresses that cause cancer”

When the researchers applied a drug that triggers this kind of stress to giant tortoise cells in a lab dish, they were surprised to see that the cells immediately self-destructed (bioRxiv, doi.org/gn33). “We thought that they might be super resistant to the kinds of stresses that cause cancer, but it ends up that they’re very sensitive,” says Lynch.

Killing damaged cells before they turn cancerous protects the animal from developing tumours, he says, adding that this is likely to be just one of many ways in which giant tortoises reduce their risk. ▮

Claire Ainsworth

Animals

Noise-cancelling genes stop bats losing their hearing

James Urquhart

ECHOLOCATING bats have noise-cancelling genes that may help explain why they don't go deaf despite emitting very loud ultrasonic sounds as they fly.

Most bats produce intense, high-pitched sounds that bounce off objects, letting them navigate and find food in the dark. These sonar calls are beyond human hearing and are often louder than 100 decibels.

A conversation between people is at about 60 decibels, but prolonged exposure to noise above 80 decibels can cause ear damage in most mammals, including us. Above 120 decibels, it becomes painful. Extreme noise can irreparably harm sensitive hair cells in a mammalian cochlea (a spiral-shaped cavity in the ear) that are required in hearing.

Echolocating bats have a muscle in their ears that dampens incoming sounds, but the effect isn't enough to explain how their hearing – which is essential for their echolocation abilities – isn't damaged by the cacophony they make when flying.

Seeking an answer, Peng Shi at the Chinese Academy of Sciences and his colleagues attached brainwave-recording electrodes to the heads of anaesthetised mice, a non-echolocating fruit bat species and five echolocating bat species. Sounds within their hearing range were then played to them at 120 decibels for 2 hours. A week later, the researchers performed the same experiment again.

Results showed that the mice and fruit bats experienced hearing loss and had lost a significant amount of cochlear hair cells, but the echolocating bats were unaffected. By comparing the genetics of bats that do and don't echolocate, the team found that the five species of echolocating bats have several genes that overproduce proteins that seem to protect their cochlear hair cells (*Journal of Genetics and Genomics*, doi.org/gnz4). ▮

Space

Methane-burping microbes may live near Curiosity rover

Jonathan O'Callaghan

NASA/JPL-CALTECH/MSSS

NASA's Curiosity rover has been sniffing for methane

AN UNKNOWN source may be producing methane close to NASA's Curiosity rover, with potential implications for life on Mars.

Since Curiosity landed in Gale crater on Mars in 2012, it has used an instrument called the Tunable Laser Spectrometer (TLS) to measure the amount of atmospheric methane in its vicinity.

For most of the time, it has recorded a very low background level of about 0.41 parts per billion. But on six occasions, Curiosity has witnessed methane spikes, in which methane levels have risen at least tenfold – with one spike registering a methane concentration of almost 10 parts per billion.

The cause of the methane spikes is unclear, so Yangcheng Luo at the California Institute of Technology and his colleagues generated a model to try to work out where they were coming from.

Taking into account factors such as the local wind speed and direction at the time a spike was detected, they were able to pinpoint a possible source a few dozen kilometres away from Curiosity inside the 150-kilometre-wide Gale crater (*Research Square*, doi.org/gnsc).

"[The results] point to an active emission region to the west and the southwest of the Curiosity rover on the northwestern crater floor," the team writes in its paper.

10

parts per billion of methane detected by Curiosity

"This may invoke a coincidence that we selected a landing site for Curiosity that is located next to an active methane emission site."

If correct, this would be the most accurate localisation of a methane source ever on Mars.

"This would make this site interesting to visit, or other similar sites that could have the same properties," says Håkan Svedhem, the project scientist for the European Space Agency's Trace Gas Orbiter (TGO), which is currently orbiting Mars.

Although Curiosity has detected methane at the surface, the TGO has found nothing in the atmosphere. The reason for this is unclear, and is perhaps linked to Curiosity performing its searches for methane at night when the Martian atmosphere is calmer. But another possibility is that Curiosity just happens to sit near a methane source.

John Moores at York University in Toronto, Canada, says it is possible this source is some sort of crack or "seep" in the surface, leaking methane from underground, but it could be hard to locate.

"It's a bit of a haystack," he says. "It could be covered by dust and be almost impossible to find."

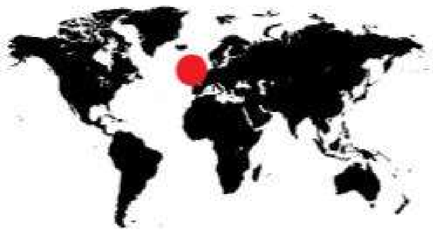
Finding the source of methane on Mars could play an important role in working out its origin. On Earth, "probably 95 per cent of methane is of biological origin", says Svedhem, and scientists have wondered if the same might be true on Mars, perhaps indicating the presence of some form of microbial life. "Our hope was that we could see sufficient amounts of it and determine if it is a biological or not biological origin," says Svedhem.

We aren't yet any closer to that yet, but with methane on Mars expected to have a detectable lifespan of no more than 300 years or so, its continued presence on Mars "indicates that something is producing methane today", says Moores. It is possible the source is geological, connected perhaps to asteroids or comets hitting Mars, but the prospect of a biological origin remains a possibility. ▮

Field notes Port Lympne Reserve, Kent, UK

Meet the puzzle-solving gorillas

Watching how great apes learn to get nuts out of puzzle boxes might help us understand the neural underpinnings of language, finds **Clare Wilson**



THERE are many ways that our great ape relatives can remind us of ourselves: through their anatomy, cleverness and social relationships, for instance. But never has the resemblance been so striking for me as today, when I watch gorillas carrying out a very human pastime: solving puzzles.

The gorillas in question live at Port Lympne Reserve in Kent in the UK. The task involves moving a hazelnut down a vertical maze using sticks or the inbuilt cogs, until it is released at the bottom.

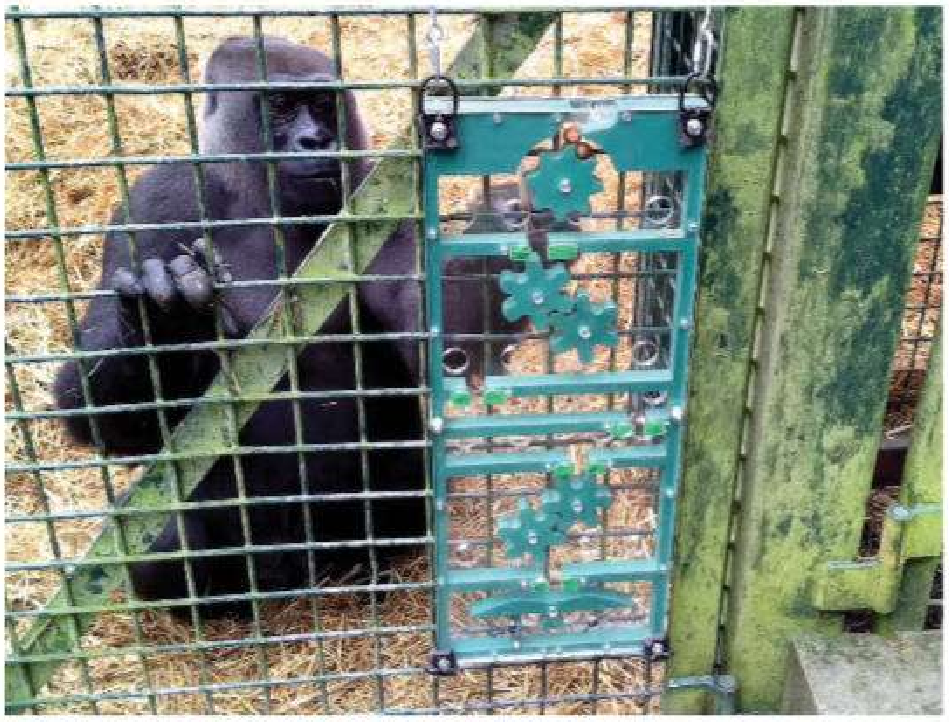
30

years since we began probing the link between tools and language

The task is part of a research project by Gillian Forrester at Birkbeck, University of London. I have tagged along, ostensibly to learn about her work, but my real goal was seeing the gorillas. Never before have I had such a good look at these animals – which are western lowland gorillas (*Gorilla gorilla gorilla*) – as some of them cannot resist coming to the front of their enclosure to work doggedly away at the mazes.

Tibs, a skilful older female, carefully selects sticks, breaks bits off to shorten them and nibbles off leaves. She determinedly moves the nuts around the course, clutching a bar for support with big leathery fingers that have surprisingly human-like fingernails. Her expression seems to reflect intense attention, like a person doing a jigsaw puzzle.

The research is investigating an idea about the origins of language. Linguists debate whether the first languages were based on hand gestures rather than grunts. But Forrester's team is investigating an even earlier stage in the process – the mental abilities that language built on. "There would have been stuff going on in our ancestors' brains that we have extended for language," says Forrester. "We're trying to learn what kind of behaviours it was supporting previously."



GILLIAN FORRESTER

Tibs, a western lowland gorilla, is an expert puzzle solver

DAVE STOCK

Gillian Forrester with a chimpanzee at Twycross zoo in the UK

One possibility, first suggested in 1991, is tool use, which has several features in common with language. They both involve sequences of precise physical movements, whether of the hands or the mouth and vocal cords. They also require breaking down a complex final goal into simpler intermediate ones and achieving those in the right order. "If you don't put your words in the correct order, the meaning will be obscured," says Forrester.

One piece of evidence is that the part of the brain that supports language in people, an area usually on the left side of the brain that is expanded compared with the right, is also involved in tool use in people and in apes and monkeys. And that left-sided expansion is also present in non-human great apes. "As they do not possess human language, this suggests the neural mechanism is older than language," says Forrester.

The puzzle boxes are designed to have similarities with the cognitive demands of language, requiring ordered sequences of physical movements. "We have simple cogs that are equivalent to words, and we have double cogs, which could be analogous to how verbs or adjectives act on a noun," says Forrester.

Her team is working with the gorillas at the Port Lympne Reserve and chimpanzees and orangutans at Twycross zoo in the UK to find out at what age the ability to solve puzzle boxes emerges, and to see if the younger individuals learn by copying adults, another shared feature of both tool use and language. The team is also testing human children, and the work could shed light on why some children have difficulties learning to talk, says Forrester.

As I watch, a 2-year-old gorilla called Vuko scurries over and observes an older female at work. Later, Vuko wiggles a finger in one of the holes experimentally, but cannot yet figure out the mechanism. I know we shouldn't anthropomorphise but I can't help seeing disappointment in her big, brown eyes.

"Language looks super-unique on the surface, but the brain processing that's going on underneath it can't be," says Forrester. "If we can understand that, it helps us understand how humans came to be." ▮

To see the gorillas in action, visit youtu.be/8edayRfe484

Cosmology

We may finally solve the mystery of how fast the universe is expanding

Leah Crane

ONE of the most frustrating questions in modern cosmology may be getting closer to an answer. The different methods we use to measure the rate of expansion of the universe have been in disagreement for years, but a relatively new measurement technique seems to be a way to resolve the dispute.

The universe is constantly expanding, and the rate at which that expansion accelerates is described by a number called the Hubble constant. There are two main ways that we determine this number: by examining the cosmic microwave background (CMB), which is a relic of the first light to shine through the universe, and by observing nearby objects to see how fast they are moving away from us. The results of those two methods have always clashed.

Now, Wendy Freedman at the University of Chicago has pioneered a new way of measuring nearby objects that may resolve the clash. To make local measurements of the Hubble constant, we use objects with known brightnesses to measure distances in what is called the distance ladder.

The most common way to do this is to use variable stars called Cepheids to find the distances to galaxies with supernovae in them, and then use supernovae to probe further out. However, Freedman used a different type of star, called tip of the red giant branch (TRGB) because of its place on charts of stellar evolution, to replace Cepheids – and the results determined from these stars match the CMB measurements.

While Cepheids are generally formed in dusty stellar nurseries, which may obscure measurements, TRGB stars can be found in the same relatively dust-free areas as the supernovae that form the next rung of the distance ladder. Freedman found that as observations probed increasingly distant objects, the Cepheids and the TRGB measurements diverged from one another. At these distances, Cepheids are obscured by dust and crowded among other stars, and it becomes more difficult to determine how their chemical make-up, or metallicity, affects the observations (arxiv.org/abs/2106.15656).

"It's not simply that the effects of dust are worse: the effects of crowding are worse, the effects of metallicity are worse, and they're all entangled. So if you get one correction wrong, you get them all wrong," says Freedman. "With TRGB stars, it's simple – there's no dust, nothing to disentangle." These stars aren't variable like Cepheids, so they are simpler and far better understood.

Supernovae help astronomers calculate cosmic distances

PANTHER MEDIA GMBH/ALAMY

The fact that replacing Cepheids on the distance ladder eliminates the tension between CMB measurements and local observations may mean there are just errors in our understanding of Cepheids. If the tension had remained, it might have meant there was some larger confusion about cosmology and the physics of the early universe that produced the CMB.

"It allows for the possibility that there is no tension, and it's just a matter of imperfect measurements," says Dan Scolnic at Duke University in North Carolina. "Some might say that incorrect measurements is the least exciting outcome of the Hubble tension, but on the other hand, it would show that our cosmological model can explain the entire expansion history of the universe."

More observations are required before we can say for sure that the tension over the Hubble constant has been ironed out, but these results provide a ray of hope that it is resolvable, says Freedman. ▮

Palaeontology

Trilobite survived a fight with giant sea scorpion

ABOUT 453 million years ago, a trilobite might have escaped the claws of a hungry giant sea scorpion, a fossil suggests.

Trilobites flourished in the oceans from around 522 million to 252 million years ago before going extinct. These hard-bodied arthropods resembled woodlice and ranged between about 1 millimetre and 70 centimetres in length.

Oldřich Fatka at Charles University in the Czech Republic and his colleagues studied an unusual eye trauma in the fossilised head of a common trilobite species called *Dalmanitina socialis* and believe it survived a predator's attack.

Casts of the fossil's surfaces enabled the researchers to see that part of the eye was missing. They think either all or part of the eye was gouged away but moultings of the animal's exoskeleton helped the wound heal and allowed a smaller eye to grow back. Other signs of injury and healing included scratches, a crescent-shaped scar and misshapen cheeks.

The most likely explanation, the researchers think, is that the trilobite was attacked by a predator. In theory, that predator might have been a larger trilobite, a cephalopod or a giant eurypterid "sea scorpion" – all were living in the region at the same time as the small trilobite (*International Journal of Paleopathology*, doi.org/gnzz).

However, the team eliminated the first two candidates because their method of inflicting damage didn't tally with the injuries. That left just one contender. Giant sea scorpions were the largest arthropods known to have ever lived, with some species reaching 2.5 metres long. They had arm-like appendages with toothed claws for grabbing prey.

"The trilobite survived to regenerate the damaged eye and surrounding cheeks"

"A failed predatory attack with the trilobite surviving to regenerate the damaged eye and surrounding cheeks really is the most likely cause," says Greg Edgecombe at the Natural History Museum in London. "It must have been this guy's lucky day." ▮

James Urquhart

Technology

Large-scale quantum computers one step closer

Matthew Sparkes

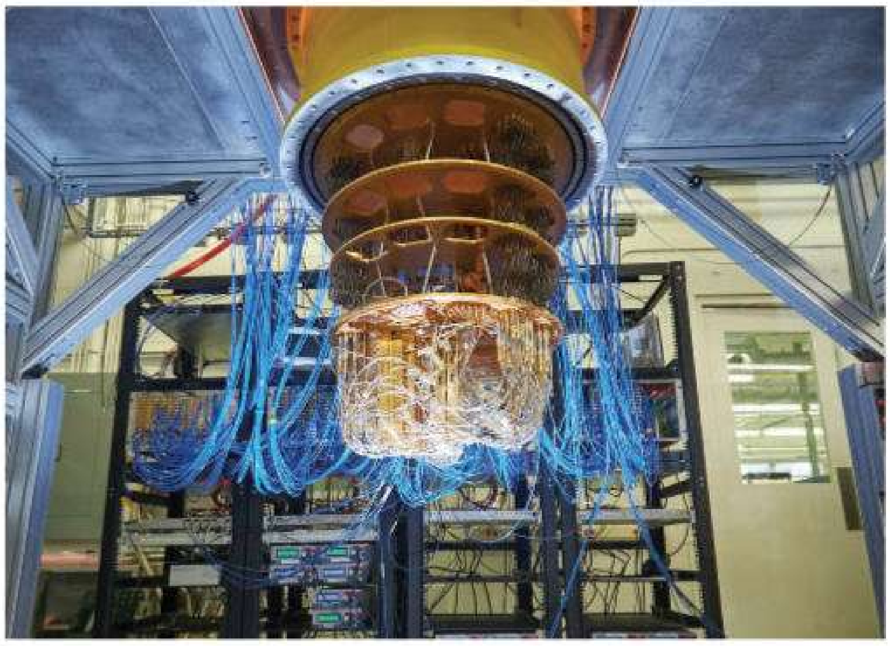
GOOGLE has shown that its Sycamore quantum computer can detect and fix computational errors, an essential step for large-scale quantum computing, but its current system generates more errors than it solves.

Error correction is a standard feature for ordinary, or classical, computers, which store data using bits with two possible states: 0 and 1. Transmitting data with extra "parity bits" that warn if a 0 has flipped to 1, or vice versa, means such errors can be found and fixed.

In quantum computing, the problem is far more complex as each quantum bit, or qubit, exists in a mixed state of 0 and 1, and any attempt to measure them directly destroys the data. One long-standing theoretical solution to this has been to cluster many physical qubits into a single "logical qubit". Although such logical qubits have been created previously, they hadn't been used for error correction until now.

Julian Kelly at Google AI Quantum and his colleagues have demonstrated the concept on Google's Sycamore quantum computer, with logical qubits ranging in size from five to 21 physical qubits, and found that logical qubit error rates dropped exponentially for each additional physical qubit. The team was able to make careful measurements of the extra qubits that didn't collapse their state but, when taken collectively, still gave enough information to deduce whether errors had occurred (*Nature*, doi.org/gk6mrd).

Kelly says that this means it is possible to create practical, reliable quantum computers in the future. "This is basically our first half-step along the path to demonstrate that," he says. "A viable way of getting to really large-scale, error-tolerant computers. It's sort of a look ahead for the devices that we want to make in the future."



ROCCO CESELIN/GOOGLE

Google is experimenting with its Sycamore quantum computer

The team has managed to demonstrate this solution conceptually, but a vast engineering challenge remains. Adding more qubits to each logical qubit brings its own problems as each physical qubit is itself susceptible to errors.

54

Number of physical qubits in Google's Sycamore processor

The chance of a logical qubit encountering an error rises as the number of qubits inside it increases.

There is a break-even point in this process, known as the threshold, where the error correction features catch more problems than the increase in qubits bring. Crucially, Google's error correction doesn't yet meet the threshold. To do so will require less noisy physical qubits that encounter fewer errors and larger numbers of them devoted to each logical qubit.

The team believes that mature quantum computers will need 1000 qubits to make each logical qubit – Sycamore currently has just 54 physical qubits.

Peter Knight at Imperial College London says Google's research is progress towards something essential for future quantum computers. "If we couldn't do this, we're not gonna have a large-scale machine," he says. "I applaud the fact they've done it, simply because without this, without this advance, you will still have uncertainty about whether the roadmap towards fault tolerance was feasible. They removed those doubts."

But he says it will be a considerable task to actually meet the threshold and build effective error correction, which would mean creating a processor with many more qubits than has been demonstrated until now. ▮

Environment

Climate change to blame for monarch butterfly decline

Adam Vaughan

CLIMATE change has been the biggest cause of the precipitous decline of the monarch butterfly (*Danaus plexippus*) in North America in recent years, say researchers who fear parts of its breeding range will become inhospitable under future warming.

The puzzle of the decline of the insect, famous for its epic migration from the US and Canada to Mexico in the winter, has been variously blamed on herbicides wiping out the milkweed plant their caterpillars feed on, to problems on their migratory route and climate change.

To test which is having the greatest impact, Erin Zylstra and Elise Zipkin at Michigan State University and their colleagues combed 18,000 mostly citizen science surveys of monarchs carried out in the US and Canada, and combined them with weather data to build a population model.

Between 2004 and 2018, the amount that rainfall and temperature deviated from the long-term average was about seven times more important than other factors in explaining the monarch's summer numbers (*Nature Ecology & Evolution*, doi.org/gn3v).

Previous research – which found a correlation between herbicide use, milkweed loss and the steepest monarch decline, from 1994 to 2003 – still stands, says Zipkin. But she says milkweed stayed "pretty constant" from 2004 to 2018, which, along with the results of the new study, indicates that climate change explains the recent decline.

The research doesn't mean conservationists should stop protecting and planting milkweed to help the butterflies. "But as we think forward [to climate change], planting milkweed may not be enough," says Zipkin. ▮

To take part in a conservation-aiding butterfly count, see page 51

New Scientist
Events

BIG THINKER SERIES

ANIL SETH

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Climate change

EU's carbon tax will apply globally

Is there really a global appetite for climate action? A new EU tax will let us know

Adam Vaughan

AN UNPRECEDENTED and controversial carbon tax will be applied to goods imported to the European Union from 2026, the flagship measure in a sweeping suite of European Commission policies unveiled last week to meet the bloc's 2030 climate target.

The tax will mean companies importing iron and steel, aluminium, cement, fertilisers and electricity to the EU will have to buy a certificate for every tonne of carbon dioxide embedded in their goods. In theory, it puts importers' costs on a par with those of firms within the EU that have to pay for similar certificates in the EU's internal carbon market.

"The idea is to put foreign producers on a level playing field," says Johanna Lehne at think tank E3G.

Formally known as the carbon border adjustment mechanism (CBAM), the scheme is the first of this scale and scope globally. The CBAM's central aim is to combat "carbon leakage", the risk of a company in the EU responding to the union's climate policy costs by relocating outside the bloc to a country that may have a cheaper, but more polluting, energy supply.

A secondary goal is to provide an incentive for non-EU countries to increase their ambition on climate change. For instance, a fertiliser firm in Turkey should have to pay lower taxes to ship its product to the EU if Ankara used policies to clean up the country's electricity grid.

However, the border tax has generated a storm of pushback even before it was officially outlined last week, with China, Australia and other countries warning against trade barriers and protectionism. It remains to be seen if the scheme can win over critics and play an important role in fighting climate change. At the most extreme end, the EU could be forced into a climbdown akin to one it made in 2012 after it included flights in its carbon market.

At a fundamental level, the tax will have to be compatible with World Trade Organization (WTO) rules. André Sapir at the Free University of Brussels, Belgium, is sure the principle of the scheme will be compatible with these rules, but the way it is implemented may be how other countries try to fight it through the WTO. "I think there will be an international legal challenge," says Lehne.

Importers to the EU may soon be taxed for their carbon emissions

EDUCATION IMAGES/UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

One surprise in the plan compared with leaked drafts is that producers outside the EU won't have to start paying until 2026. But they will have to start reporting their products' carbon from 2023 to the end of 2025.

Globally, some international development groups will be disappointed that the tax makes no exemptions for the world's poorest countries, which are concerned the measure goes against the multilateral spirit of climate efforts such as the Paris Agreement.

But for all its potential flaws, the carbon border tax is a bold new way to try fighting climate change, and even its existence will make a difference. "This would be the first time carbon pricing applied to producers in a jurisdiction is applied to those outside," says Sapir. "That in itself is an incredibly huge step." ▮

Technology

3D-printed steel bridge takes the load in Amsterdam

THE first ever 3D-printed steel bridge has opened in Amsterdam, the Netherlands. It was created by robotic arms using welding torches to deposit the structure of the bridge layer by layer, and is made of 4500 kilograms of stainless steel.

The 12-metre-long MX3D Bridge was built by four commercially available industrial robots and took six months to print. The structure was recently transported to its location over the Oudezijds Achterburgwal canal in central Amsterdam and is now open.

More than a dozen sensors attached to the bridge after the printing was completed will monitor strain, movement, vibration and temperature across the structure as people pass over it and the weather changes. The data will be fed into a digital model of the bridge.

Engineers will use this model to study the properties of the unique material and will employ machine learning to spot any trends in the data that could indicate maintenance or modification is necessary. They also hope it will help designers understand how 3D-printed steel might be used for more complex building projects.

Mark Girolami at the University of Cambridge, who is working on the digital model with a team at the Alan Turing Institute in London, says investigations into bridge failures often reveal deterioration that was missed. Constant data feedback may have been able to prevent these failures by providing an early warning, he says.

"The 12-metre-long MX3D Bridge was built by four industrial robots and took six months to print"

Girolami says early indications for the strength of 3D-printed steel are positive. "What was in some sense surprising was that the baseline strength was what you would expect of just rolled steel." ▮

Matthew Sparkes

Welcome to our Signal Boost project – a page for charitable organisations to get their message out to a global audience, free of charge. Today, a message from **Alzheimer's Research UK**

Revolutionising early detection of Alzheimer's

Currently, diseases like Alzheimer's are diagnosed when symptoms such as memory loss start to show. Sadly, by this stage the disease has been quietly taking hold of the brain for up to two decades. To have the best chance of halting these diseases, we need to identify early signs and intervene, protecting the brain and preventing symptoms so they never get in the way of life.

Digital technology can pick up subtle early changes in the way we behave – our sleep, speech, interactions and movement – that are undetectable to the human eye.

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Our researchers are collecting and analysing vast amounts of clinical and digital health data, identifying digital fingerprints that pinpoint early disease using data from smartphones and wearables like watches and headbands.

We imagine a day when our digital toolkit could give you and your doctor information about your risk of diseases like Alzheimer's later in life. This information would open the door to prevention and allow you to take part in clinical trials to speed up the search for life-changing treatments.

Ultimately, this technology would impact the lives of millions of people around the world, reducing the number of families affected by dementia.

Find out more

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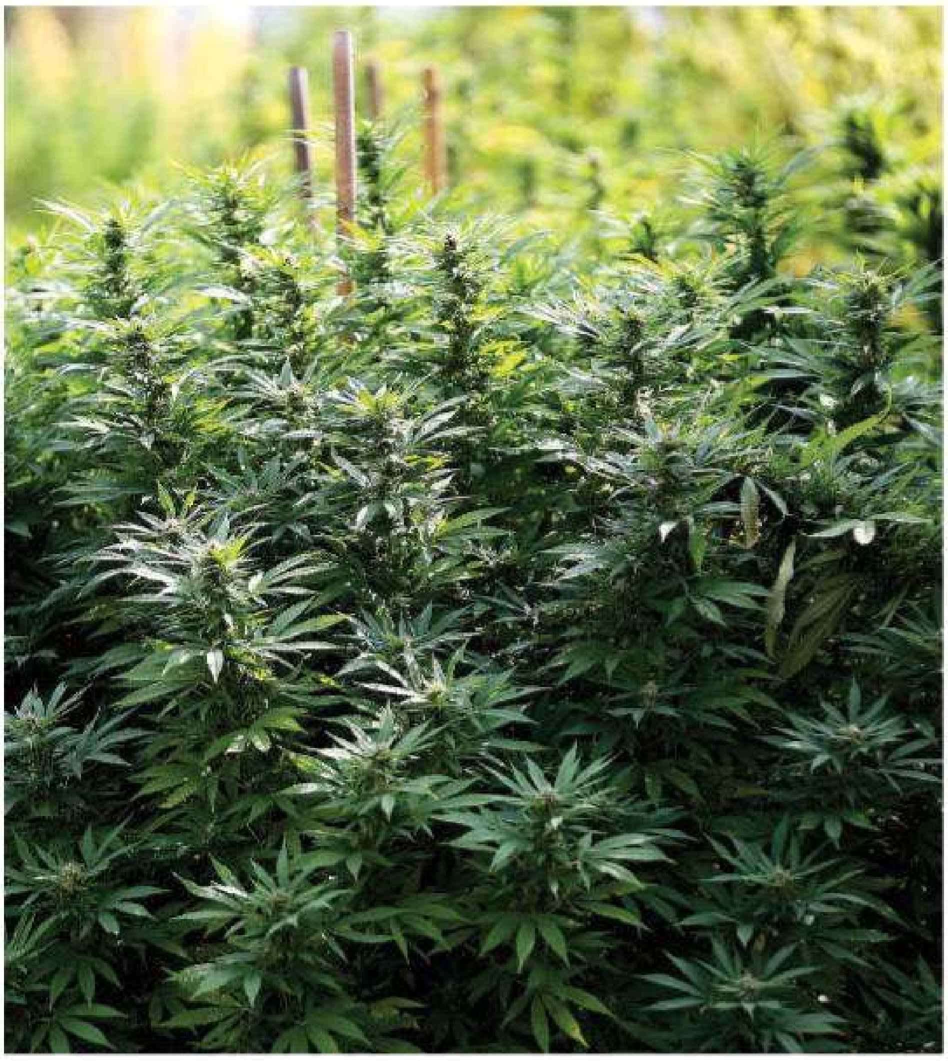

REUTERS/ALESSANDRO BIANCHI

Botany

Cannabis was domesticated 12,000 years ago in China

AN ANALYSIS of the genomes of 110 plants from around the world shows cannabis was domesticated in what is now north-west China about 12,000 years ago.

"It confirms it is one of the oldest cultivated plants," says Luca Fumagalli at the University of Lausanne, Switzerland. "It was exploited for fibre, food and oil, and possibly medical and recreational purposes."

Little has been known about the domestication of *Cannabis sativa* because it is hard to get hold of strains for genetic studies. "You can't just go and collect samples because you go to jail," says Fumagalli. So he worked with people around the world to collect and sequence some 80 kinds of cannabis plants that are cultivated or growing wild. The team also included 30 previously sequenced genomes in the analysis.

The wild ancestor of cannabis seems to be extinct, but strains in north-west China are its closest living relatives, the team found. The genomic dating of around 12,000 years fits with archaeological evidence of pottery with hemp cord markings on it from around this time.

It was only about 4000 years ago, the study suggests, that people started breeding distinct strains for drug or fibre production. The team identified genetic mutations that make plants more suitable either for producing fibre, resin or tetrahydrocannabinol – its main psychoactive substance (*Science Advances*, doi.org/gnzn). The work should help breeders optimise commercial strains.

Michael Le Page

Infectious diseases

Spotting infection just by looking at you

PEOPLE across cultures can tell when others are in the early stages of infection by looking at them.

Artin Arshamian at the Karolinska Institute in Stockholm, Sweden, and his colleagues tested whether it was possible to tell if someone was sick just by looking at photos of their face.

The team worked with 169 volunteers from six different cultural backgrounds, including city dwellers in Stockholm and hunter-gatherers in the rainforests of Thailand and Malaysia, and in the coastal deserts of Mexico. Each volunteer was shown photos of Swedish people taken 2 hours after they had been injected with either *Escherichia coli* or a placebo.

Those who had been injected with *E. coli* were at the beginning stages of an immune response when their photos were taken, and some of the volunteers in all six groups had a better-than-chance ability to identify that they were sick.

The ability to tell who is sick at an early stage could help us decide whether to avoid certain people, says Joshua Tybur at VU University Amsterdam in the Netherlands.

"The most dangerous thing is if you get contact with pathogens that your immune system has little experience with," says Arshamian. "Basically, this is what happened to the Native Americans."

The team had thought that the volunteers from Stockholm would do best at recognising sickness because the photos were of people from their own community, but this wasn't the case (*Proceedings of the Royal Society B*, doi.org/gk6hzc).

"I think what it means is that probably this is such a stable ability and such a general ability that cultural experience probably doesn't affect it that much," says Arshamian. **Krista Charles**

Technology

3D-printed hand plays *Super Mario Bros*

A 3D-PRINTED robotic hand controlled by pressurised water can complete the first level of classic computer game *Super Mario Bros* in less than 90 seconds.

Ryan Sochol at the University of Maryland and his team 3D-printed the hand using a machine that can deposit hard plastic, a rubber-like polymer and a water-soluble "sacrificial" material. The last material enables complicated shapes to be supported during construction before it is rinsed away when printing is complete.

This makes it possible to create the rigid skeleton of the device and "fluidic circuits" that are operated by a single source of pressurised water, and that turn streams of water into finger movements.

The hand's three fingers are each triggered by different pressures sent along a single control hose. This means that by controlling the pressure of water pulses, the team could move each of the three fingers and operate a game controller with enough precision to play the game (*Science Advances*, doi.org/gk7rph).

The device cost just a few pounds to manufacture and was created using a commercially available 3D printer.

Sochol says that soft robotics like this can be powered by safe sources like pressurised water or air, and may lead to advances in prosthetic limbs.

Matthew Sparkes

UNIVERSITY OF MARYLAND

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Really brief

MAGNUS MOLLER/ALAMY

Coal powers some bitcoin mining

Levels of bitcoin mining in Kazakhstan increased from 1.4 per cent of the global market share to 8.2 per cent in recent months, following the introduction of government restrictions on bitcoin mining in China. Kazakhstan has a power grid fuelled largely by coal, so bitcoin mined there has a higher carbon footprint.

Just 7 per cent of our DNA is unique to us

Modern humans have evolved since appearing 350,000 years ago – but just 1.5 to 7 per cent of our DNA is unique. The rest we shared with Neanderthals and Denisovans. Some was inherited through our common ancestors, some gained via interbreeding (*Science Advances*, doi.org/gnzh).

Drones to be used to fight crime in Dubai

Dubai police will be able to respond to an incident anywhere in the United Arab Emirates city within 1 minute, thanks to a network of pre-positioned drone bases. The quadcopters, supplied by Israeli company Airobotics, will be used during the delayed Expo 2020 event later this year.

Wearable technology

Finger sweat could power health sensors

SMALL biofuel cells can harvest enough energy from the sweat on our fingertips to power wearable medical sensors that track health and nutrition, and because our fingertips are one of the sweatiest parts of the body, the sensors could be powered all day.

Lu Yin at the University of California, San Diego, and his colleagues created a device that breaks down a dissolved compound in sweat called lactate. It comprises biofuel cells that fit into thin pads stuck to the fingertips. They soak up sweat into a thin layer of foam, where an enzyme oxidises lactate to create an electrical charge.

Each finger pad can generate between 20 and 40 microwatts of power and harvest 300 millijoules of energy per square centimetre during 10 hours of sleep (*Joule*, doi.org/gnrq). This isn't enough to run devices like smartwatches or mobile phones, but it is for lightweight sensors that detect metrics such as heart rate, vitamin deficiencies and glucose levels.

Previous devices powered by sweat needed large volumes of it, but fingertips produce a small, continuous amount even if you aren't exercising.

"Even with the minute amount of sweat compared to the sweat you got from a really intense workout, this power is still very sizeable," says Yin.

Currently, the enzyme that is key to the reaction begins to break down and become ineffective after two weeks. Yin says that further research is needed to create a stable enzyme that can be used in permanent sensors. **MS**

Health

KARLA ANN COTE/NURPHOTO VIA GETTY IMAGES

Legal levels of lead in US tap water can still cause harm

DRINKING water containing levels of lead below the threshold that warrants regulatory action in the US may be associated with worse health in people with kidney disease.

"For individuals with heightened susceptibility to lead exposure, such as those with chronic kidney disease, there is no safe amount of lead contamination of drinking water," says John Danziger at Beth Israel Deaconess Medical Center in Massachusetts. He and his colleagues analysed health data on 597,968 people with chronic kidney disease in the US who started dialysis between 2005 and 2017, as well as data on lead concentrations in city water systems.

People who lived in cities with detectable levels of lead in the water had lower concentrations of the oxygen-transporting protein haemoglobin in their blood before starting dialysis than people who lived where lead wasn't detectable. Lead interferes with the ability of blood cells to produce haemoglobin, increasing the risk of anaemia.

The trend was seen even at lead levels below the US Environmental Protection Agency's regulatory threshold of 0.015 milligrams per litre (*Journal of the American Society of Nephrology*, doi.org/gnr3). **Layal Liverpool**

Mathematics

Printed shape tests out 150-year-old idea

A STRANGE shape described by mathematician Lord Kelvin in 1871 and predicted to behave unusually in a fluid has finally been studied thanks to 3D printing, and it seems Kelvin may have been wrong.

The shape, called an isotropic helicoid, was expected, like a sphere, to experience the same amount of drag regardless of its orientation but also rotate as it moves through a fluid. So if you dropped one into a tank of a viscous liquid, it should spin as it sinks, much as a propeller turns.

Greg Voth at Wesleyan University in Middletown, Connecticut, and his colleagues 3D-printed five shapes that should be isotropic helicoids, each a little more than a centimetre across, and dropped them in a tank of silicone oil. They were unable to detect any rotation, so the predictions for an isotropic helicoid may be wrong (*Physical Review Fluids*, doi.org/gnr7).

"You've got to guess that somebody else has tried this in 150 years," says Voth. "I suspect that people have tried to fabricate these particles, but they were limited by defects in the fabrication so they simply didn't publish, so the hypothesis of this behaviour has stayed with us." **Leah Crane**

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Views

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The dark thriller *Katla* leaves viewers emotionally raw **p32**

Comment

Halt the mineral rush

We have just two years to stop a potential environmental disaster due to deep-sea mining. Here's how we do it, says **Helen Scales**

MICHELLE D'URBANO

FIFTY years ago, people started dreaming of mining the deep seabed. Since then, those dreams have turned into a dystopian nightmare as scientists have found diverse, interconnected ecosystems at the bottom of the ocean and realised that mining them risks upsetting the health and functioning of our planet.

We have yet to start deep-sea mining, so this dystopia is just one version of the future, but it is one that may soon get the green light. Countries such as the UK, France, Belgium, Jamaica, Russia, China and Japan all have their sights set on the metals inside coal-sized nodules scattered across a vast abyssal plain, called the Clarion Clipperton Zone, 5000 metres underwater in the Pacific Ocean.

But turbocharging things is the Pacific island state of Nauru, which has used a controversial provision in international law to declare that its seabed-mining contractor, a subsidiary of Canadian-owned The Metals Company, intends to apply for a mining permit. The vague provision means that in two years' time the International Seabed Authority shall "provisionally approve" Nauru's nodule mine, which would operate according to the environmental regulations in place by then – which could be none. These are currently being discussed and are nowhere near ready.

If seabed mining were to go ahead, it could unleash an environmental disaster. Nodule mines could wipe out unique species and populations. Sediment plumes could choke animals, including those living far from the mines. Mining wastewater could pollute deep open waters. From tardigrades to tuna, octopuses, corals and whale sharks, nodule mining could harm a huge array of ocean life.

Nauru's mine could be quickly followed by dozens more run by other countries and corporations, impacting thousands of square kilometres of seabed every year for decades. What's more, it could pave the way for mining giant underwater mountains and hydrothermal vents, which are home to their own astonishing and little-known ecosystems.

Besides the immediate destruction, deep-sea mining could have far wider impacts, disrupting climate regulation, nutrient cycling and long-term storage of carbon in the ocean. And if pending environmental catastrophe isn't alarming enough, mining could damage ecosystems that contain understudied chemicals with huge potential for new medicines.

However, deep-sea mining isn't inevitable. That is why I have joined hundreds of other scientists and policy experts in calling for a global moratorium. Our Deep-Sea Mining Science Statement outlines a case for a pause on mining until we understand what the full impacts would be, and is open for additional signatures from anyone who wishes to show their support.

Achieving such a move before the two-year period is up will be challenging, but we are optimistic it can happen. A promising avenue looks to be through the UN General Assembly, which has precedent. Its non-binding resolution on high seas drift netting led to a moratorium on this fishing technique, which kills huge numbers of dolphins, whales, sea turtles and seabirds. An equivalent UN resolution for a seabed-mining moratorium could also encompass a wider mining strategy to responsibly meet the demand for minerals needed by the rise in green technologies.

Momentum for a moratorium is growing, with support from civil society, corporations, the fishing sector and financial institutions. In June, the European Parliament strengthened its backing for a moratorium and called on the European Commission and EU member states to join it. Numerous bilateral conversations are already happening.

We must take this step to add the deep seabed to the short list of relatively untouched regions on Earth, alongside Antarctica, that are too important and too fragile to open up and exploit. And we must do so soon. ▮

Helen Scales is a marine biologist and author of *The Brilliant Abyss: True tales of exploring the deep sea*

Field notes from space-time

The eternal debate about eternal inflation

The idea that the universe is continually inflating isn't confirmed and there are still some misconceptions about it, writes **Chanda Prescod-Weinstein**

Chanda Prescod-Weinstein is an assistant professor of physics and astronomy, and a core faculty member in women's studies at the University of New Hampshire. Her research in theoretical physics focuses on cosmology, neutron stars and particles beyond the standard model

LAST month, I wrote a column about the possibility that space-time is eternally inflating, and I was admittedly caught off guard by the amount of attention it got on social media. I am pleased that so many people share my interest in cosmology and specifically the first few seconds of space-time as we understand it.

At the same time, I was troubled by a supposed summary of the column that I saw in another publication which claimed I was proposing a new theory for the origins of the universe. This suggests to me that I should continue my discussion of inflation this month, including explaining my relatively minor role in doing research on it.

To start, it is worth saying again that my primary research focus is on the problem of dark matter, which we think comprises up to a quarter of the matter and energy in the universe. The cosmology and particle physics communities have been studying dark matter for about 50 years now, and while we have learned a few things about it, there is still much that we don't know about the elusive substance.

The primary site of our ignorance is what exactly dark matter is. Is it a new particle? If so, what are its properties? Or is it comprised of primordial black holes? And is the fact that we know so little abut it just a sign that our theory of gravity is broken?

Whatever dark matter turns out to be, there is also the matter of the timeline: when did dark matter first arrive on the cosmological scene?

It is here that dark matter as a problem can be linked to the question of what happened to space-time in the early universe, and it isn't unusual for theoretical physicists who work on ideas in response to one question to dabble in solutions to the other, and possible links between the two. In my case, around the time that I began working on dark matter, I also got involved in a bit of research about a cosmological era called reheating.

In my opinion, reheating doesn't get enough attention from us physicists. Inflation itself is quite flashy: a short moment, in our part of the universe anyway, where space-time rapidly expands. Reheating, by contrast, is "just" the aftermath of inflation, when the universe is very cold and it needs to literally reheat and fill with the particles that form the structures we observe today, about 14 billion years later. That's clearly not as flashy as inflation, but it is still fascinating.

"In this scenario, once inflation starts, most of the universe is always inflating, and only small parts of it may ever stop"

Our current best guess about how reheating happened is that at the end of inflation, the particle that drove the process, called the inflaton, still had some leftover energy. This energy decayed into the particles that eventually formed the atoms we see today.

It might sound as if we have it all worked out, but what I have told you is in some sense a very smart guess. We don't have good observational evidence – yet – from this time period. And we don't know if, for example, dark matter first started to form during this era.

For my part, I am intrigued by efforts to build models that address dark matter and reheating simultaneously, but my own research has focused on the possible outcomes for reheating if there are several different species of inflaton, which is a realistic expectation from the point of view of particle physics. There is no reason it has to be just one particle.

That is the extent of my work on inflationary models: I think about everything that happens after. This isn't to say that inflation doesn't continue to be an interesting moment on the cosmological timeline – and there are still many unanswered questions about it.

Though we have a sense of how it works, we are still unsure of the equations that correctly describe it. There is also disagreement about eternal inflation – the idea that inflation continues forever. In my last column, I pointed out that this process can occur eternally into the past and the future.

There are some people, like Alan Guth, the physicist who first developed the theory of inflation (and my former postdoctoral adviser), who have argued that it is eternal into the future only, meaning that there may have been an originating big bang. In this scenario, once inflation starts, most of the universe is always inflating, and potentially only small parts of it (like ours) ever stop.

Other physicists, like my master's degree adviser Anthony Aguirre, have claimed that inflation goes in both directions. It is under Anthony's guidance – back in 2003 – that I first learned about the subject, which means I am a bit biased about what we mean when we talk about "eternal inflation".

But, importantly, my last column was hardly about a new proposal, and I can't be given credit for the idea either. ▮

Chanda's week

What I'm reading

Intersectionality as Critical Social Theory *by Patricia Hill Collins has an excellent explanation of the differences between critical theory, critical race theory and critical social theory.*

What I'm watching

I finally finished The Haunting of Bly Manor *and enjoyed it.*

What I'm working on

I am beginning edits and updates for the paperback edition of my book The Disordered Cosmos.

This column appears monthly. Up next week: Graham Lawton

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Editor's pick

On the latest thinking about consciousness

10 July, p 34

From Luce Gilmore, Cambridge, UK

The suggestion that consciousness might be substrate-dependent – in other words, that protoplasmic brains can be conscious but silicon can't – is an example of vitalism, the idea that living things have properties that are inexplicable by the rules of physics and chemistry.

This concept has been in retreat since 1828, when Friedrich Wöhler made the bodily substance urea from inorganic ammonium cyanate. Given centuries of progress in genetics, biochemistry, neurology and so on, vitalism can only be deemed mysticism. The requirements of consciousness aren't exotic: self-awareness, attention and memory are probably all that are necessary, though integrating these functions may call for ingenuity.

Consciousness-generating hardware may already be feasible (maybe it is already being built). To save expense, the hardware could be emulated in software. You could probably impose consciousness on a Sinclair ZX Spectrum, one of the first home computers. It would take thousands of years to form a single thought, but presumably it wouldn't notice the sluggishness any more than we notice the rattle of our own thinking machinery.

From Eric Kvaalen, Les Essarts-le-Roi, France

You ask: "Is consciousness detectable in the brain?" The answer is: not always. People can have conscious experiences when their brains are "flatlining" (see, for example, the near-death case of Pam Reynolds). Any theory of consciousness that can't account for such facts is insufficient.

If some of the theories for consciousness are correct, then brain organoids are conscious and we shouldn't be playing with them. Conversely, if organoids aren't conscious, then those theories are incorrect and the question remains: what makes us conscious and not them?

Softer pavements will have unintended downsides

10 July, p 46

From Richard Harries, Rishworth, West Yorkshire, UK

You report the idea of making pavements softer and safer. As a full-time wheelchair user, I spend a lot of time looking at the surface I am about to wheel over. I suspect a softer surface will require more effort to push on, much as hard, dry, close-cropped grass does, possibly inversely in line with the findings you mentioned on foot pressure in volunteer joggers.

As minority users, it will be up to us to find some minor tweaks in wheelchair design and technology to try to reduce this effort. While softer may be safer, it will cost some of us more.

Is this why doctors are downplaying pain?

26 June, p 25

From Rosemary Sharples, Sydney, Australia

The account of J. S.'s pain not being taken seriously because she was a woman will resonate with many women on many levels.

I have come to the conclusion that, as well as displaying the prejudices against women described in the article, some doctors feel the unknown is a threat they can't handle, so they ignore it and hope it will go away.

Views on the call to rewrite genetic terms

10 July, p 23

From Bryn Glover, Kirkby Malzeard, North Yorkshire, UK

I greatly welcome geneticist Adam Rutherford's attempts to clean up the language of his profession, but I fear for his success.

Some 40 years ago, I tried a very similar thing for the membership of one of the UK's largest trade unions. My simple (and, as I saw it, reasonable) thesis was that as the English language is rich and complex, then it ought to be a simple matter to find alternative expressions that don't give offence.

The reactions were immediate and intense. The phrase "political correctness" had recently come into vogue and was extensively bandied, even in some national newspapers. Our members generally condemned the effort as pedantic and patronising.

I do hope Rutherford has much greater success, but I suspect that the conservative attitudes of his fellows will win the day.

From Denise Taylor, London, UK

It is a basic mistake to imagine that forbidding words has the power to forbid thoughts. I would rather current geneticists spent their time on breakthrough genetic research than language choices.

Geoengineer the oceans? That's a no from me

3 July, p 13

From Paul Whiteley, Bittaford, Devon, UK

Regarding the plan to dump iron in the oceans to promote plankton growth to capture carbon. This implies we must modify the chemistry of the oceans on a global scale so that fossil fuel companies don't have to change their business models and politicians can kick those difficult decisions into the long grass.

Should we be dabbling with feedback loops that we either don't fully understand or even know exist, and will take us heavens knows where should we get it wrong? No!

I fear the rise of a really bad variant in England

Leader, 10 July

From Arthur Barnett, London, UK

You say that the lifting of all coronavirus restrictions in England is a gamble. I agree.

Covid-19 variants have, to date, emerged from locations with high infection rates and zero or low vaccination rates, including Kent, UK, in 2020. Government policy in England appears to be intent on creating a new scenario with both high infection rates and high full and partial vaccination rates, creating an environment for a different variant to emerge that could reduce the efficacy of current vaccines to a great degree.

I, too, have long-lasting symptoms after vaccine

Letters, 10 July

From Linda Phillips, Narrogin, Western Australia

Robert Law writes of long covid-like symptoms in his 40-year-old daughter after coronavirus vaccination and asks if others have had the same experience.

Yes! I thought it was just me! I had the Oxford/AstraZeneca jab on 14 June, at the age of 68. That night, I had violent shivers. In the four weeks since, I have had headaches, "fog", breathing difficulties and lethargy, feeling dizzy if I attempt even low levels of exercise. Are any researchers studying the impact and recovery rates of people after vaccination?

The swimming platypus has no need to glow

8 May, p 41

From Nina Dougall, Malmsbury, Victoria, Australia

Glowing in the dark will remain a platypus mystery. These animals close their eyes when swimming underwater and find prey with their sensitive "rubbery" bills. ▮

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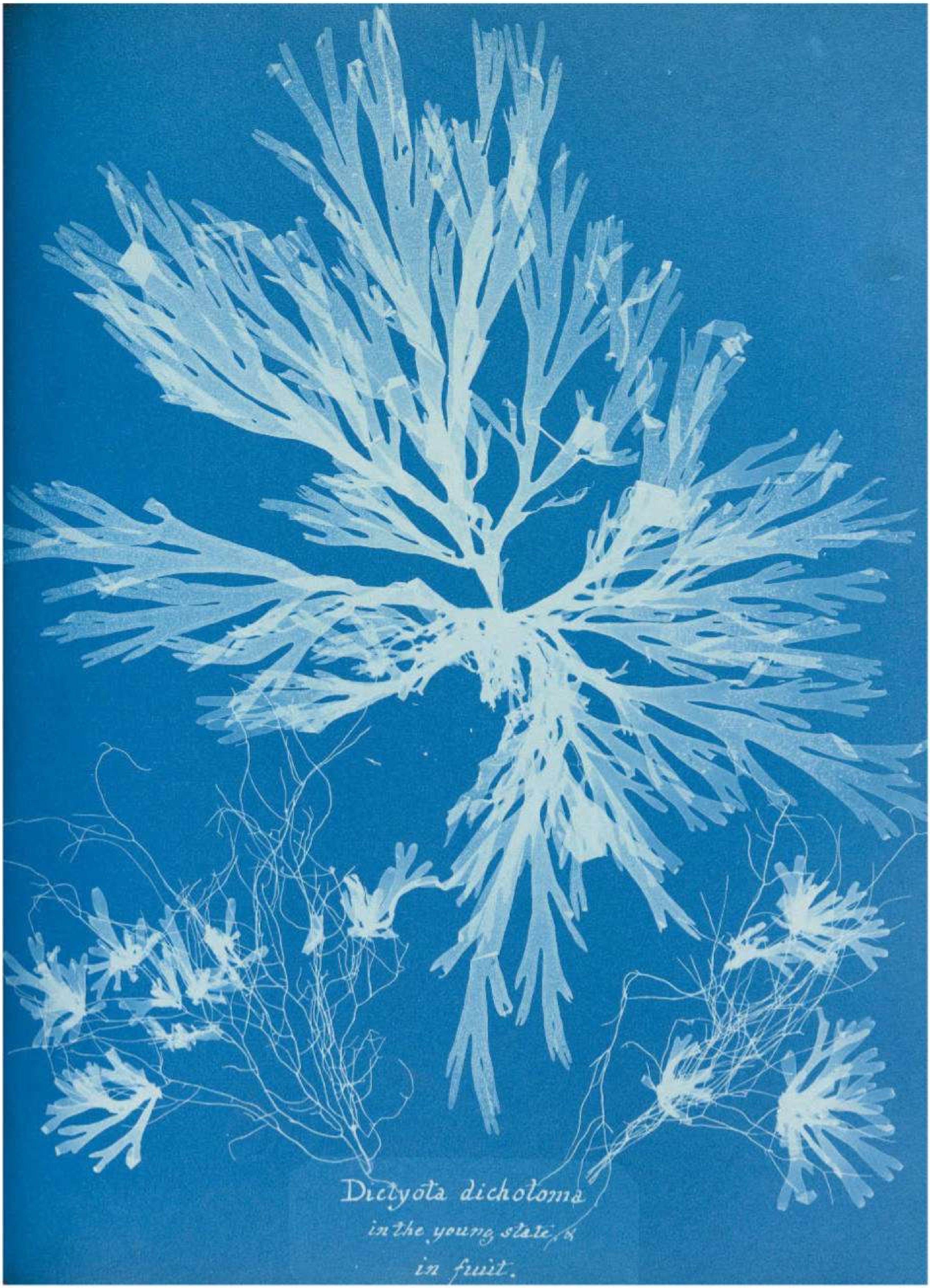

ANNA ATKINS/HORNIMAN MUSEUM AND GARDENS

KAZUMASA OGAWA/DULWICH PICTURE GALLERY

CHARLES JONES/DULWICH PICTURE GALLERY

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First for nature

Unearthed: Photography's Roots, Dulwich Picture Gallery, London

THESE impressive images include some of the first photographs of nature, taken from Unearthed: Photography's Roots, an exhibition tracing the history of photography from the 1840s to the 21st century through depictions of plants and botany. The exhibition is showing at Dulwich Picture Gallery, London, until 30 August.

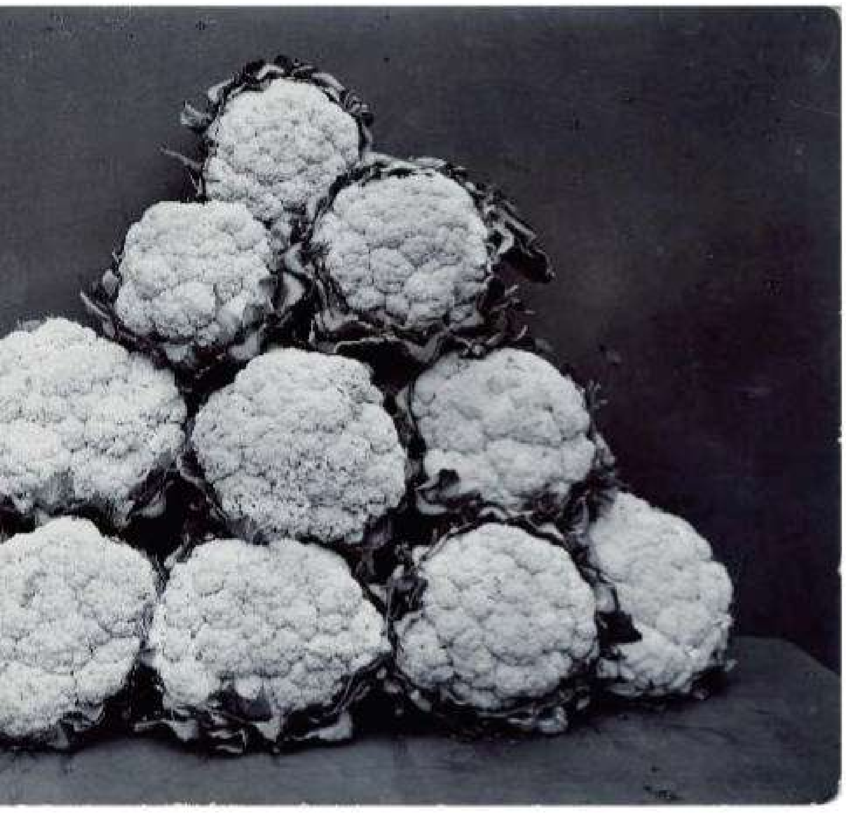
The largest image (left) shows a species of brown algae called Dictyota dichotoma, or forkweed. It is a cyanotype, a photographic print in which paper coated with iron compounds creates a rich blue image when exposed to light, and it was taken by Victorian botanist and photographer Anna Atkins. She produced more than 400 images of algae between 1843 and 1853, and is thought to have been the first person to illustrate a book with photographic images.

Next to it (centre, top) is an image of chrysanthemum petals, taken by photographer Ogawa Kazumasa in 1894. Directly below it, Charles Jones's shot of a stack of broccoli was achieved using gelatin silver printing, a technique developed in the 19th century.

Jones used the same method to capture the image of a bean pod (right, top). Directly below it is a shot of some peas by artist Gyula Holics, who also used gelatin silver printing.

The image at the bottom of this column shows a vase of poppies, taken by Richard Learoyd in 2019 using an ancient device called a camera obscura. This is created by making a tiny hole in one wall of a small, dark room, which acts as a lens and projects an image of whatever is outside onto the wall opposite the hole.

Gege Li



CHARLES JONES/DULWICH PICTURE GALLERY

GYULA HOLICS

RICHARD LEAROYD/MATTHEW HOLLOW

Naturally high

Opium, caffeine and mescaline shaped the world for millennia. An intriguing book tracks their influence through the experiences of its author, says **Gege Li**

Book

This is Your Mind on Plants: Opium, caffeine, mescaline
Michael Pollan
Allen Lane

YE AUNG THU/AFP VIA GETTY IMAGES

A farmer works an illegal poppy field in Myanmar

TRY to think of an area where plants haven't benefited us and you will probably come up short. But as well as providing us with food, medicine and textiles, they are a source of psychoactive drugs. These mind-bending, state-altering substances lurk in plants everywhere. For millennia, they have been at work on the human mind, behaviour and lifestyle.

Even so, we have only begun to understand how this relationship shaped our history, says journalist Michael Pollan in *This is Your Mind on Plants*. In a narrative that is part memoir, part reportage, he probes this complex relationship, and how and why such plants have become embedded in our lives.

Pollan examines the sedative morphine, found in the opium poppy; the stimulant caffeine, found in tea and coffee; and the hallucinogen mescaline, found in certain varieties of cacti. All three are bitter-tasting alkaloids, evolved by plants as a form of defence. But, as Pollan makes clear, they have become important parts of human culture.

The book's first section, about opium, is told mainly through Pollan's eyes and is based on an article he wrote in 1997, when the US war on drugs was at its peak. Pollan describes how he tried growing opium poppies after coming across the book *Opium for the Masses* by Jim Hogshire, which told people how to extract opium from poppies at home.

What follows is a turbulent journey into the legal, if murky, world of opium at the time. Buying poppy seeds and growing the plants is allowed, Pollan finds, but beyond that the rules become more opaque. He does succeed in cultivating (and sampling) his homemade version of the drug.

Of Pollan's trio, caffeine is the most widely used substance, with about 80 per cent of the world's population consuming it. Many become hooked on its ability to keep us alert – Pollan included.

To probe the effects of caffeine on mind and body, he decides to stop drinking it temporarily, while he explores the rich and often shocking history of coffee and tea. Their energising influences have fuelled advancements in learning and thought, while huge demand from consumers led to an increase in the transatlantic slave trade, for example, with coffee growers in Brazil bringing enslaved people from Africa to their plantations.

BRIAN JACKSON/ALAMY

Coffee has a rich and often shocking history

Caffeine is what Pollan calls "one of the cleverest evolutionary strategies ever chanced upon by a plant". Thanks to the global dependence on coffee and tea, "these two have also assisted in the construction of precisely the kind of civilization in which they could best thrive", he writes.

The final section is on mescaline, a consciousness-altering psychedelic contained in the seeds of cacti including the peyote and San Pedro cactus. It largely focuses on the religious, spiritual and cultural importance of the drug to Indigenous people in the Americas.

Mescaline has been used by these groups for more than 6000 years, making it the oldest known psychedelic, and its effects are recounted through Pollan's experiences with it, as well as its use in traditional ceremonies.

In that sense, *This is Your Mind on Plants* delivers on its title more through the anecdotes and self-experimentation of Pollan and others than by providing hard facts. The book points to the far-reaching impact (and sometimes domination) of plant drugs on human history, culture and thinking, and Pollan seems to have become an advocate for the personal use of drugs derived from plants. As he writes: "I've come to appreciate that when we take these plants into our bodies and let them change our minds, we are engaging with nature in one of the most profound ways possible."

"Coffee and tea plants have assisted in the construction of the kind of civilization in which they best thrive"

Ultimately, while his book is thoroughly researched, it may not satisfy those looking for the precise scientific detail of exactly what it is they do to our minds. ▮

Gege Li is a writer based in London

Amazing animal senses

The wealth of invention in the natural world is mind-blowing. Take the spiders that rebuild their eyes to hunt, says **Simon Ings**

Book

Secret Worlds: The extraordinary senses of animals

Martin Stevens

Oxford University Press

ECHOLOCATING bats use ultrasound to map out their surroundings at night. That information is fine-grained, helping them distinguish between the wing cases and body of a beetle and the wings of a moth. The high frequency of ultrasound generates clearer sonic images than sound in our hearing range would. Be glad bats use it, because they are seriously noisy. A single bat out for a meal screams at about 140 decibels. A human, shouting a metre away, generates only 90 dB.

This is the kind of extraordinary sensory ability celebrated in *Secret Worlds* by Martin Stevens, at Exeter University in the UK. It is a popular version of his textbook *Sensory Ecology, Behaviour, and Evolution*, but with important extras. While paying its dues to those amazing abilities of animals, *Secret Worlds* has some very intriguing things to say about the evolution and plasticity of the senses – and above all, the cost of acquiring them.

"Rather than seeing countless species all around us, each with every single one of their senses being a pinnacle of what is possible," he writes, "we instead observe that evolution and development has honed those senses that the animal needs most, and scaled back on the others."

Stevens presents startling data about the expense involved in sensing the world. For example, a full tenth of the energy used by a blowfly (*Calliphora vicina*) at rest is spent maintaining the photoreceptors in its eyes and associated nerve cells.

He also highlights some remarkable energy-saving strategies. For instance, the nocturnal ogre-faced spider (*Deinopis subrufa*) from Australia has such large, sensitive eyes that it must break down its photoreceptors and membranes during the day, and regenerate them to hunt at night.

Senses are too expensive to stick around when they aren't needed, so they disappear and reappear over evolutionary time. In evolutionary terms, their genetic mechanisms are surprisingly parsimonious with the same genetic pathways cropping up often, and in unrelated species.

While Stevens's main point is nature's parsimony, it is the wonderful extremes that will stick in most minds. For instance, the whiskers of a harbour seal (*Phoca vitulina*) help it find a buried flatfish using nothing more than the water flow created by the fish's breathing.

Even more arresting are the chapters devoted to senses wholly unfamiliar to us. Using their infrared thermal receptors, vampire bats select particular blood vessels to bite into. Many marine species detect minute amounts of electricity, allowing them to hunt, elude predators and attract mates.

As for animals' ability to use Earth's magnetic field, Stevens reckons "it is no exaggeration to say that understanding how [it] works has been one of the great mysteries in biology". There are two main theories to explain it: one relating to the presence of crystals in the body that react to magnetic fields; the other to light-dependent chemical processes occurring in the eyes in response to magnetic information. The robin complicates the picture because it seems to boast both systems, one for use in daylight and one for use in the dark.

And what of satellite images of cows and deer that show herds lining themselves up along lines of magnetic force, their heads pointing to magnetic north? One can only hope that Stevens will return with fresh insights in a few years. ▮

GERHARD KOERTNER/AVALON.RED/ALAMY

The ogre-faced spider remakes its photoreceptors by day to hunt at night

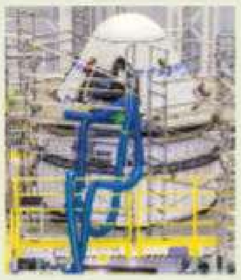
Don't miss

Watch

Lessons from plants is an online talk by botanist Beronda Montgomery, who argues that how plants adapt will be key to our future. Live streaming on 27 July at 7pm BST, Royal Institution, London.

Play

Wind & Leaves from virtual reality developer Trebuchet is released on 27 July for PlayStation VR. It invites you to bring a barren planet back to life, equipped only with some basic tools and a thirst for adventure.



Watch

NASA's Boeing Orbital Flight Test 2 is your chance to join NASA at the start of its uncrewed mission to test Starliner and the Atlas V rocket system, from launch to docking to landing. It starts at 2.53pm EDT on 30 July.

TOP: BLICKWINKEL/R. KOENIG/ALAMY; MIDDLE: TREBUCHET; BOTTOM: BOEING

The deep mystery of Katla

In Vík, an Icelandic coastal town, missing people are emerging from a deadly volcano. What follows is a compelling tale, says **Robyn Chowdhury**

TV

Katla

Created by Baltasar Kormákur

Netflix

LILJA JONSDOTTIR

Katla is a dark thriller about the secrets of an Icelandic volcano

Katla is a story about a community living in the shadow of a glacial volcano that has been erupting for more than a year. The series is named after that volcano, but it isn't just about the threat of disaster: when people presumed missing or dead start showing up, things take a mysterious turn.

The show takes us on a supernatural journey that deals with the impacts of grief and trauma, and combines them with folklore elements and a sprinkling of sci-fi. This Netflix original series was created by award-winning director Baltasar Kormákur and shot in the Icelandic coastal town of Vík, which borders the real-life Katla.

The first episode introduces us to several overlapping storylines – a woman covered in ash emerges out of the blue, another woman grapples with the loss of her sister, and a team of scientists works towards understanding the changing geology of the volcano.

The interesting thing about *Katla* is that no single character or plot line is the focus. Gríma (Guðrún Eyfjörð) and her father Þór (Ingvar Sigurdsson) are some of the first people we meet and the significance of their story, concerning Gríma's missing sister Ása (Íris Tanja Flygenring), is hinted at early on.

But by the second episode, the strange woman Gunhild (Aliette Opheim) who appeared on the volcano leads us down yet another intriguing avenue, when we discover that she is the younger version of an existing woman. This is only the beginning of a plot that raises questions about who we really are and what makes us, us.

As the trend of ash-covered people emerging from the volcano continues, the tension within Vík's community increases. Each new character brings their own traumatic backstory, and the fantastic acting of every single member of the cast makes these emotionally driven narratives even more compelling.

The people of Vík seem intensely affected by grief, but the way they deal with this ranges from denial to obsession – and sometimes has gruesome consequences. Gríma's attempts to get to grips with the reappearance of Ása, who had been assumed dead, makes for one of the most harrowing tales. Eyfjörð delivers such an emotional performance that you really feel her pain, particularly in the finale.

> **"When people presumed missing or dead start showing up, covered in ash, things take a mysterious turn"**

Despite the grief, *Katla* isn't without romance. But these liaisons often show how love can make us cruel and self-centred. Gísli (Þorsteinn Bachmann), the town's semi-competent police chief, has a complex relationship with his sick wife that adds drama to the latter part of the series.

Unfortunately, the other romantic storylines are less engaging, but still highlight the choices we have to make when it comes to love – be they selfless or selfish. This is also displayed in familial relationships, particularly between Gríma's relatives, who are as relatable as they are dysfunctional.

The subtle foreshadowing in *Katla* will leave you feeling like you almost understand what is going on, but every episode adds a little more intrigue and even less clarity. Yet this mystery isn't annoying – and if you do find yourself getting frustrated, wait for the final two episodes of the season, in which we and the characters finally learn some of the truth about Katla.

By the penultimate instalment, you are so immersed that you almost forget about the eruption itself. It is only when the scientists, led by Darri (Björn Thors), go off to study the rocks that you remember Katla is at the heart of the show.

Though it could be described as slow-paced, new characters and story elements are added every episode, keeping you captivated. The picturesque landscape adds an immersive element to the series and eerie music creates an incredible sense of unease. No moment is wasted – each scene develops the plot, or provides tension or foreshadowing.

Katla is a thriller with such depth that some episodes, particularly the fast-paced season finale, can leave you feeling genuinely raw. It is a story about grief with unpredictably dark twists, worthy of multiple watches. ■

Robyn Chowdhury is a writer based in Sheffield, UK, who is interested in pop culture and social justice

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Chris Packham is an award-winning naturalist, television presenter, writer, photographer, conservationist, campaigner and filmmaker.

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PHOTO LEFT: DAMIANKUZDAK/ISTOCK

Information and the future of defence

Our future prosperity is intimately linked to the cyber environment and the forces that operate within it. We asked a panel of experts to assess the implications for the future of defence

Earlier this year, the UK government set out ambitious plans for the country's future prosperity, its security and its role on the international stage over the next decade or so. These plans, *The Integrated Review 2021*, include significantly increased investment in science and research, a greater focus on security both at home and overseas and more emphasis on resilience for our economy and our society against all manner of threats, from climate change to cyberattacks.

By 2030, the government wants the UK "at the forefront of global regulation on technology, cyber, digital and data". In doing so the UK aims to protect itself and other democracies, and "to bolster the UK's status as a global services, digital and data hub, maximising the commercial and employment opportunities for the British people."

This places a renewed focus on the role that information plays in our economy, in our defence and in our society at large and sets out a commitment to ensure that individuals, companies and government departments can operate securely in cyberspace.

But how best to achieve that? What kind of infrastructure should the UK build to cope with cybersecurity threats? How will it handle the increasing pace of change in the cyber environment, and the threats and opportunities it presents? And how can the UK create a secure digital environment?

These questions were the focus of a recent New Scientist Debate on *Information and The Future of Defence*, sponsored by BAE Systems. The debate brought together a panel of experts to discuss the new threats facing the UK and how it can provide the cybersecurity to cope with the online world of the 2020s and beyond.

THE DATA CHALLENGE

One of the big challenges for UK's armed forces and its new National Cyber Force is to constantly analyse enormous amounts of data to identify and tackle emerging threats.

"Even on individual platforms, you can be assimilating gigabits and terabits of data at any one time," said Dave Short from BAE Systems. "But then you have to turn that into information that can flow and be centralised," he added. "It's also about getting that data to where it needs to be."

A combination of artificial intelligence, machine learning and more joined-up approaches are crucial to ensuring threats are separated from non-threats, and that that information is acted upon in a timely way.

This is challenging on the battlefield, not least because there are different communications networks and standards across land, sea and air forces, in multiple NATO allies. "If information is to flow around the battlefield, everything needs to be able to talk to everything else," said Steven Meers from the UK's Defence Science and Technology Laboratory. "It's a real challenge to ensure we've got the interoperability between military platforms." This is a significant engineering challenge in modernising the armed forces with the aim for data to travel "at the speed of relevance".

Gathering information has always been crucial to defence: whether through spying, or through technologies like satellites and the internet where huge amounts of data are generated and circulated every second. Handling that data, both its volume and its complexity, is crucial for identifying threats and responding. New threats are emerging rapidly: cyberattacks on organisations increased 400 per cent over 2019 and 2020 – partly driven by the shift to remote working caused by the pandemic.

Protecting society from these attacks is partly about speed. "The speed of warfare is changing dramatically," said Dave Short, Technology Director at BAE Systems. In the past, defenders would have minutes or even hours warning of an impending attack. "In the cyberworld that can be down to seconds or microseconds, in which you have to detect, identify and respond effectively."

But information sources are also changing. "The information age has flipped how the armed forces use information," said Steven Meers, head of the artificial intelligence (AI) lab at the Defence Science and Technology Laboratory at Porton Down, part of the Ministry of Defence. 20 years ago, he says, 80 per cent of the data came from defence platforms and sources, with 20 per cent from elsewhere. Now it's the other way around and these diverse data sets have to be drawn together and assessed quickly and correctly.

Another complication is the huge diversity of groups who launch cyberattacks and other threats. Sometimes attacks are state-sponsored, sometimes they are purely criminal, with several shades of grey between them.

"Increasingly information is becoming weaponised," said Meers. He gives an example from November 2015 when a video appeared online that seemed to show a US

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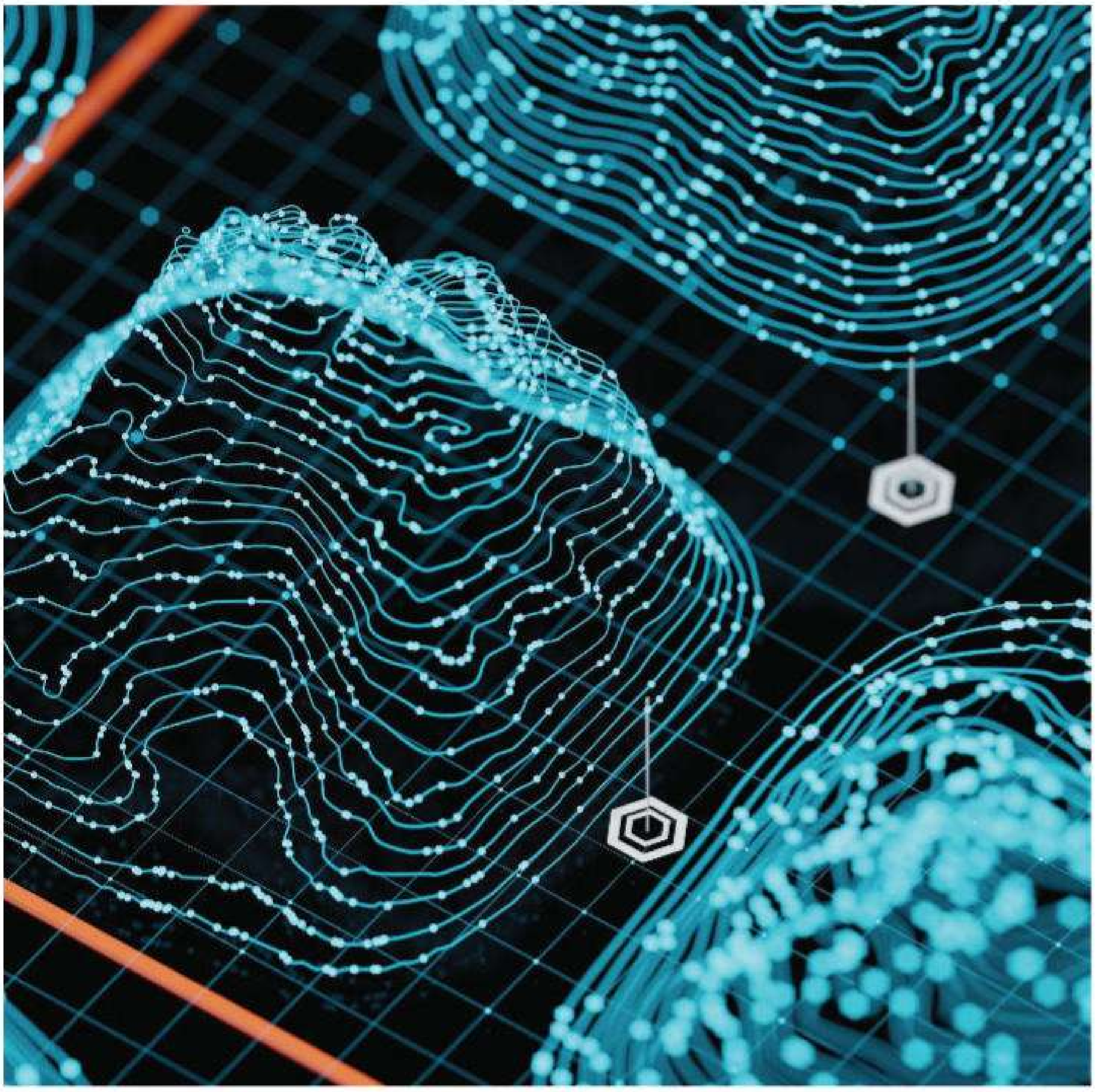


KOTO FEJA/ISTOCK

soldier shooting a copy of the Quran. This was inflammatory and incendiary, says Meers, causing immense problems for US forces in Afghanistan.

Two days after the event, the US issued a comprehensive rebuttal of the video showing that the soldier wasn't wearing a current military uniform or even using a US rifle. The video had been faked. "But the damage had already been done," said Meers

Emerging technologies like AI and machine learning have key roles to play in identifying genuine threats and misinformation in the deluge of data. The panel agreed that for now, AI is likely to be limited to highly specific tasks but that some of these tasks raise serious ethical issues

Earlier this year, New Scientist reported that military drones may have for the first time, autonomously killed humans during a confrontation in Libya in 2020. The situation was complex, so it is not entirely clear whether the drones acted without human intervention, but if the line has not yet been crossed, we are clearly edging closer to it.

Ethical framework

The panel felt strongly that such life-and-death decisions need human input. "It's important we develop models where humans and AI systems can work together effectively," said Nick Jennings, professor of AI at Imperial College London, and the government's Chief Scientific Advisor for National Security 2010-2015.

But Short pointed out that while the UK has taken the clear and ethical position to always keep a human-in-the-loop over the use of autonomous assets, we will have a significant challenge if our adversaries create systems that make decisions more quickly without human oversight."

In all matters involving data handling, there is a growing consensus that organisations must be governed by the four principles of fairness, accountability, transparency and ethics, said Dame Wendy Hall, professor of computer science at the University of Southampton and chair of the Ada Lovelace Institute. "This has to apply to defence and security as much as it does to anything else."

While the public .cannot know all the information that government has, because some of it is necessarily secret, the principles for handling it should be both known and democratically established.

In the long run, this will require international agreement to regulate cyberwarfare: a kind of Geneva Convention for cyberspace. Hall wants to avoid a continual escalation of cyber attack and defence. "We've got to start thinking about the global rules we can get people to sign up to."

For the time being, though, the arms races continue – including in quantum computing, which has the potential to render some forms of cryptography obsolete. So while brokering international agreements on cyberconduct will be crucial, it will also be crucial that the UK develops its own capabilities. ▮

Watch the full debate at: bit.ly/3hT2cr4

The Information and the Future of Defence panel (clockwise from top left): **Steven Meers**, head of the AI Lab, Defence Science and Technology Laboratory; **Dame Wendy Hall**, professor of computer science, University of Southampton; **Nick Jennings**, professor of AI, Imperial College London; **Dave Short**, Technology Director, BAE Systems; **Justin Mullins**, Chair, *New Scientist*

Earth's chemical crisis

Synthetic pollutants flooding ecosystems are a forgotten environmental emergency – and we're struggling even to grasp the scale of the problem, reports **Graham Lawton**

IT IS the 29th century and Earth is a dump. Humans fled centuries ago after rendering it uninhabitable through insatiable consumption. All that remains is detritus: waste mountains as far as the eye can see.

This is fiction – the setting for the 2008 Disney Pixar movie *WALL-E*. But it may come close to reality if we don't clean up our act. "We all know the challenge that we've got," says Mary Ryan at Imperial College London. "We can find toxic metals in the Himalayan peaks, plastic fibres in the deepest reaches of the ocean. Air pollution is killing more people than the current pandemic. The scale of this is enormous."

Back when *WALL-E* was made, pollution and waste were near the top of the environmental agenda. At the 2002 Earth Summit in South Africa, global leaders agreed to minimise the environmental and health effects of chemical pollution, perhaps the most insidious and problematic category. They set a deadline of 2020 (spoiler alert: we missed it).

Recently, climate change and biodiversity loss have dominated environmental concerns, but earlier this year the UN quietly ushered pollution back to the top table. It issued a major report, *Making Peace with Nature*, declaring it a third great planetary emergency. "Do I think that is commensurate with the risk? Yes, I do," says Ryan.

"It justifies being right up there at the top," says Guy Woodward, also at Imperial. The key question, though, is what pollutants we should be worried about. "Many are innocuous. Some aren't. Some interact in dangerous ways. That is what we need to grapple with," says Woodward.

Pollution, the waste by-product of our economic activities, is as old as civilisation itself. Ice cores from Greenland contain traces of lead and copper from ore smelting in Bronze Age Europe. The first synthetic chemicals – ones that don't exist in nature – were created in the mid-19th century.

But as with most planet-trashing human activities, the rate at which we created new pollutants and dumped our waste products into the environment began to rise exponentially after the second world war in a 70-year, ongoing bender that has been called the "Great Acceleration".

Pumping out poison

Its waste products are many and various (see "What a load of rubbish", right), but synthetic chemicals and their products in particular have become embedded in our lives like never before. In 1950, global production of plastics, for instance, was just 1.5 million tonnes. In 2017, it was 350 million tonnes. In 2050, it is forecast to reach 2 billion tonnes. Chemical industry output in developing economies increased more than sixfold between 2000 and 2010, says the UN report. According to the International Council of Chemical Associations (ICCA), a trade body, 95 per cent of goods rely on some form of industrial chemical process in their manufacture.

›

MARCIN WOLSKI

WHAT A LOAD OF RUBBISH

Humans have become prodigious producers of unwanted stuff, including synthetic chemicals, smoke, sewage, greenhouse gases, dust, scrap machinery, food waste, e-waste, metals, plastics, glass, paints, worn-out tyres, construction materials, agricultural waste, household garbage, old clothing and packaging, to name a few.

Airborne pollutants, including carbon dioxide, nitrogen oxides, ozone and particulate pollution, come from stuff we burn to power electricity generation and industrial processes, heat buildings, cook food and fuel vehicles – as well as being released by tyres rubbing on roads. Much of the rest of our polluting trail is just what is left over when we have used whatever we want to use.

“We take stuff out of the environment, and then we put it into the economy and society – which is a fine thing because it enables us to have the life we have – but when we’re done with it, we discard it as waste back into the environment,” says Inger Anderson, executive director of the UN Environment Programme.

Reliably quantifying these sources of waste is almost impossible. According to Imperial College London’s Transition to Zero Pollution programme, however, the world economy now consumes 100 billion tonnes of raw materials a year – mainly newly extracted minerals, metals, fossil fuels and biomass.

About half goes into making long-lasting products such as infrastructure, cars and machinery. The rest creates shorter-lived products such as food, clothing and plastics, which typically have a lifespan of a year or less and are then thrown away.

Only about 10 per cent of this waste is recycled. The rest goes to landfill or is dumped into the environment. A single piece of waste may contain many different types of environmental pollutant. Discarded electrical products, for instance, often contain heavy metals, flame retardants and other synthetic chemical pollutants. If these leach into soils or water courses, they can have untold effects on our health and the surrounding ecosystems (see main story).

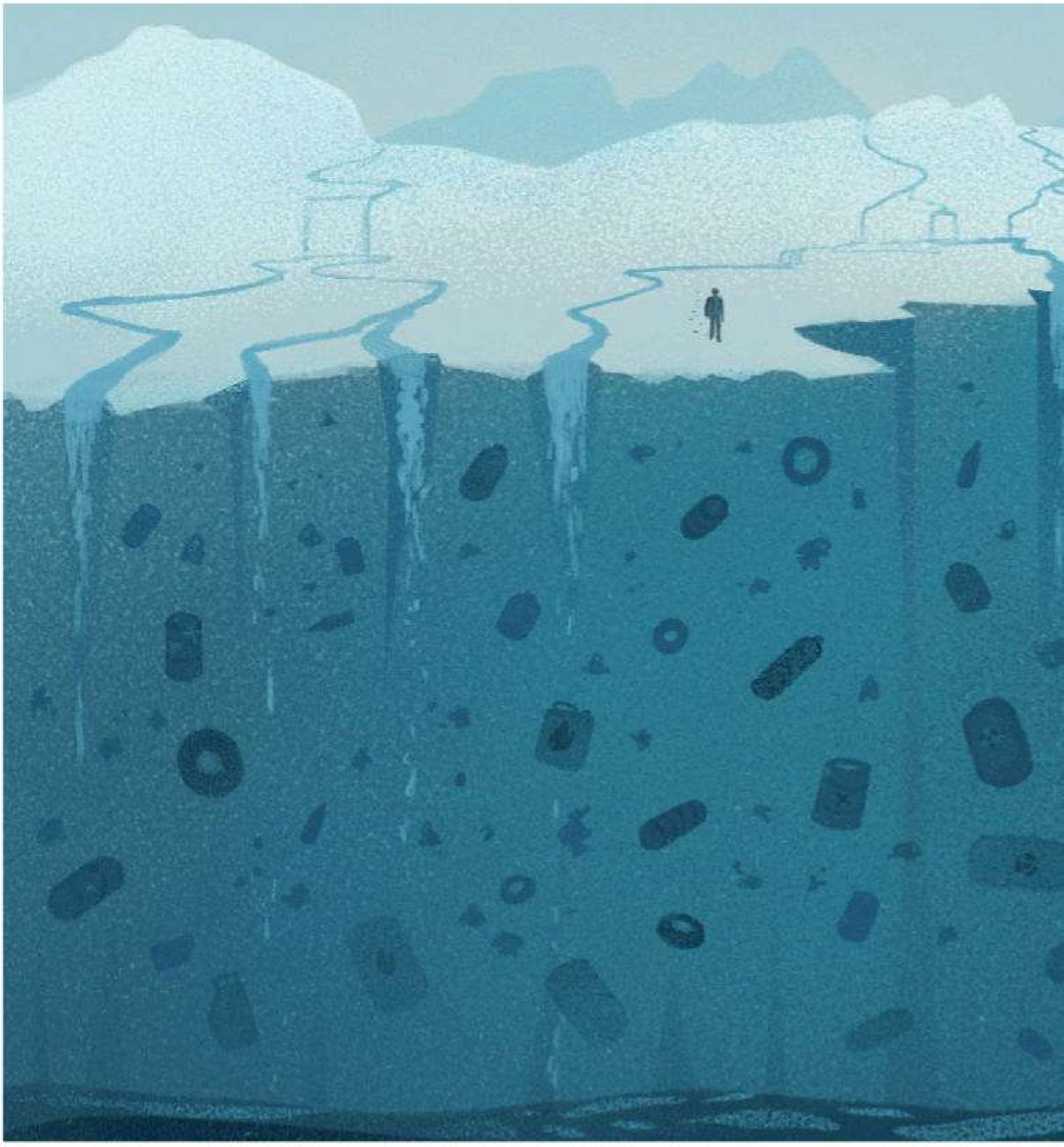
HOW MANY CHEMICALS ARE OUT THERE?

Long-standing estimates for the number of different synthetic chemicals that humans have produced range from 25,000 to 140,000, with a widely quoted ballpark figure of 100,000.

In 2019, a study by Gregory Bond of environmental consultants Manitou View Consulting in Michigan and Véronique Garny of the European Chemical Industry Council trade body suggested the true number is probably towards the bottom end of that range. They estimated that between 40,000 and 60,000 industrial chemicals are currently being made and sold in Canada, China, the EU, Japan and the US. These five places collectively produce 75 per cent of the world's chemicals and so probably account for the majority, says Bond.

But when Zhanyun Wang at the Swiss Federal Institute of Technology in Zurich and his colleagues looked further afield, at chemical inventories from the EU and 19 countries including Australia, China, India, Japan, Mexico, Russia, South Korea and Switzerland, they came up with a figure of 350,000. "We found a really surprising number," says Wang. Many researchers think it isn't far wrong.

Bond disagrees. He says this number includes about 260,000 chemicals that may no longer be manufactured or sold, and thousands more registered but never marketed. He suggests a comparable number from Wang's study is closer to his own: 69,000. One thing we can say with certainty is that there are a lot of chemicals out there.



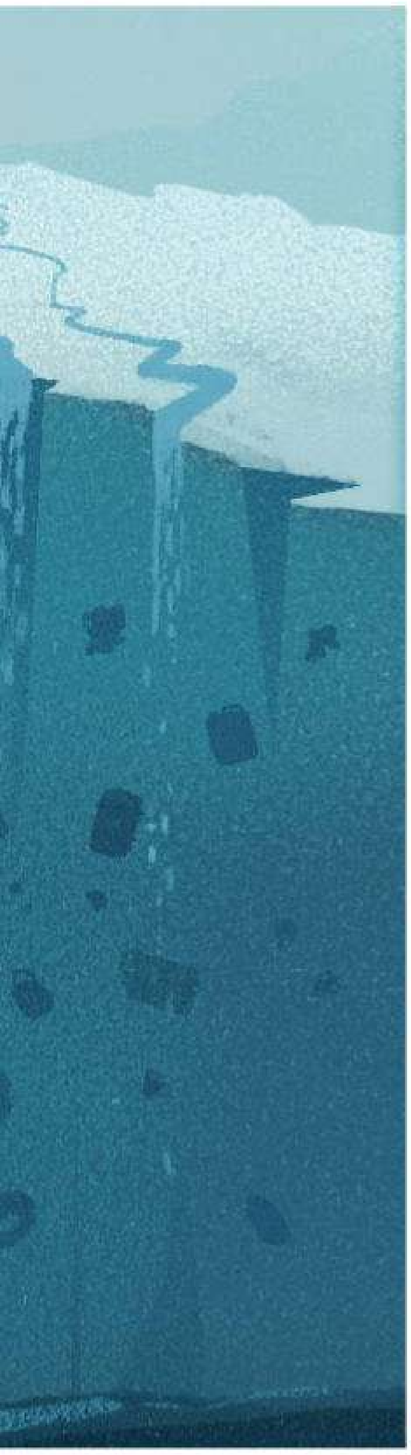
At every stage of their life cycles, synthetic chemicals can, and do, escape into the wild, potentially poisoning the environment, wildlife and us. "They are everywhere," says Zhanyun Wang at the Swiss Federal Institute of Technology in Zurich. The most visible manifestation is plastic waste, but that is the tip of a huge iceberg, he says. "We release a lot of chemicals. But we really didn't check them first."

Pinning toxic effects on any one substance or group of substances is often difficult, but many chemicals in widespread use are known or suspected to be toxic to humans and wildlife. They include substances such as polychlorinated biphenyls (PCBs), a class of industrial coolants and lubricants that can be

KNOWN NASTY

Asbestos

Asbestos is a group of silicate minerals used mainly as a fire retardant and thermal insulator in buildings. The damage it causes to our lungs if inhaled was recognised in the 1890s, but the first bans weren't put in place until the 1960s. Most countries still allow its use, including the US.



KNOWN NASTY

Heavy metals «‹

There is no universally accepted definition of a heavy metal, but most lists include lead, mercury, chromium, arsenic and cadmium. All of them can be toxic in certain forms, are widely used in industry and are released by the combustion of fossil fuels. Various efforts have been made to minimise exposure, such as the removal of tetraethyl lead from petrol, but even some sources that feel like long-solved problems are still with us.

A recent report by the UN Environment Programme, for example, flagged "lead in paint" as an ongoing concern. That same report also highlighted the dangers of cadmium and its compounds, which are highly toxic and carcinogenic at very low levels. Cadmium has myriad industrial uses including in batteries, alloys, pigments, solar cells and as an additive in PVC. It can also be a contaminant in food, because it is found in phosphate-rich rocks used to make fertiliser. Some countries and regions try to restrict its use. Global exposure to cadmium hasn't fallen over the past decade, however.

powerful disrupters of the endocrine system if ingested, and some per- and polyfluoroalkyl substances (PFASs) used principally to make stain-repellent coatings (see boxes "Known nasty" on these pages and following pages).

One particularly stark, well-documented example is a population of killer whales off the west coast of the UK that has failed to reproduce for almost 30 years and appears doomed to extinction. One mature female washed up dead on the shoreline of the Scottish island of Tiree in 2016 was found to have an undeveloped uterus and PCB levels 100 times the toxicity threshold for marine mammals. These are "astronomical levels", says Paul Jepson at the Zoological Society of London Institute of Zoology.

It isn't that we have stood entirely idly by as this has happened. Under the terms of the Stockholm Convention on persistent organic pollutants, which came into force in 2004, most countries around the world have committed themselves to outlaw or severely restrict the use of the most toxic chemicals. The original list comprised a "dirty dozen" of the worst offenders: eight pesticides (including aldrin, dieldrin, DDT and mirex), two industrial chemicals (PCBs and hexachlorobenzene) and two classes of industrial by-products (dioxins and furans).

That list has now more than doubled in length, and the Stockholm Convention is considered a relatively successful example of a multilateral environmental agreement, although its assessment procedures have been criticised as out-of-date.

But the chemicals it restricts are just a drop in the ocean. We don't even know the number of synthetic chemicals that are, or have been, on the market, although that number is many tens of thousands at least (see "How many chemicals are out there?", left). Chemicals phased out long ago may last in the environment for years, further complicating things. "Very persistent chemicals, like PFASs and like plastic pollution, will take hundreds or thousands of years," says Wang.

Woodward points out that once the chemicals are in the environment, they can react with other compounds and be transformed by living organisms, forming mixtures and breakdown products that may have different effects. Take such factors into account and there are "orders of magnitude" more chemicals to worry about, says Leon Barron, also at Imperial. We know nothing about most of these.

This lack of knowledge is matched, or even surpassed, by our ignorance about what risks most of these chemicals might pose to human health and the environment. "For some of the newer chemicals such as pharmaceuticals and pesticides, we know very little about their health effects, certainly for humans. Very, very little," says Barron. In advanced economies such as the European Union, manufacturers that want to introduce a new chemical must now convince regulators that it isn't hazardous. The EU's rules, known as REACH, came into force in 2007 and operate on the precautionary principle – a presumption that chemicals are guilty until proved innocent. But the rules don't apply to chemicals released before 2007.

In other parts of the world things are considerably laxer. To make matters worse, in many cases manufacturers keep information confidential, citing intellectual property rights, or the documentation is ambiguous. And when you factor in mixtures and breakdown products, says Woodward, "the vast majority of chemicals we know virtually nothing about".

Various organisations around the world maintain their own most-wanted lists. One ›

KNOWN NASTY
Highly hazardous pesticides

In 1962, Rachel Carson drew the world's attention to pesticide toxicity in her book *Silent Spring*. Back then, the World Health Organization estimated that about a million tonnes of pesticides were being used annually; that figure is now six times higher.

Compounds designed to kill or disable undesirable organisms have often turned out to be more widely toxic. A list of more than 300 "highly hazardous pesticides" is maintained by the global Pesticide Action Network. Earlier this year, it called for an urgent phase-out of these chemicals by 2030.

PIXEL 8/ALAMY

A worker sprays vines with the pesticide DDT in Dalmatia, Croatia

of the most useful, says Barron, comes from the European Water Framework Directive and lists both well-established nasties and emerging concerns. This list is a useful guideline for research, and has some success stories under its belt, says Barron. It flagged up the danger of neonicotinoid pesticides to bees and other insects and set the ball rolling on a near-total ban in the EU agreed in 2018. But even with these known knowns and known unknowns, it is almost certain that there are unknown unknowns too, says Wang.

The current system for assessing chemical toxicity certainly isn't up to the magnitude of the task. It typically takes a single chemical and investigates its effects on two or three organisms. There is no way we can do that for every single known synthetic chemical, let alone for breakdown products and mixtures of chemicals too. "The sun would die before we get there," says Woodward. Another problem is that lab toxicology tests aren't very informative about how a chemical will behave in a complex real-world environment, he says.

Many of the chemicals aren't even necessary. Because of intellectual property conflicts, companies often invent new chemicals to do the same job as one already out there, says Ryan. Others are there for non-essential purposes. Plastic food packaging is often dyed black for aesthetic reasons, but the dye makes the plastic unrecyclable, says Wang; personal care products often contain bulking agents such as microplastics which are dirt cheap, but potentially harmful.

Even when we do find out that a chemical is harmful, cleaning it up often isn't an option. "Unfortunately, with our current technologies, it is just impossible," says Wang. "And also financially impossible. Even cleaning up PFASs in drinking water in the US is a trillion-dollar task."

If that doesn't sound bad enough, there is a fear that, if we continue pumping chemicals into the environment with little idea of what they are or what they do, we may reach a point of no return. The idea of chemical pollution tipping points has been around for more than a decade in the form of a concept called "planetary boundaries". Formulated in 2009 by Johan Rockström at Stockholm University in Sweden, these can be thought of as limits to Earth's habitability that we overshoot at our peril. One of the boundaries is chemical pollution, which is described as "a priority for precautionary action and for further research".

As yet, it hasn't even been possible to quantify where the boundary lies. "It is a wicked problem," says Ryan. "Chemical pollution in totality is an extraordinarily complex system to try to come up with a sensible boundary on. I guess you could end up with a list of chemicals and what you think their boundary is, but even working out where those are is really hard."

Wang agrees. "It is really difficult to assess where the boundaries are and it's a daunting task," he says. "But if we have more hold on how many chemicals have been produced, have been used and what they are, then there might be some methods to help us to understand."

What we need, says Gregory Bond at environmental consultants Manitou View Consulting, is a global inventory that contains information about how, where and in what quantities chemicals are used, plus any known hazards. Wang goes further, suggesting an international body modelled on the Intergovernmental Panel on Climate Change (IPCC) to marshal and synthesise all the evidence on chemical pollution and feed it to policymakers. Biodiversity has such a body too,

KNOWN NASTY
CFCs

Action against chlorofluorocarbons (CFCs) and other ozone-eating chemicals, used principally as refrigerants and aerosol propellants, is a rare success story showing what international action on chemicals can do. A multinational environmental treaty, the Montreal Protocol, which came into force in 1989, is slowly closing the holes punched in the atmosphere's ozone layer by these chemicals. The ozone layer is projected to return to pre-CFC glory by about 2070.

the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Creating one for pollution would be in keeping with its status as the third global crisis, says Wang. He and others laid out the argument in a recent opinion piece in the journal *Science*; an accompanying campaign for support has already attracted more than 1700 signatures from 80 countries.

This and other campaigns appear to be cutting through. The UN is gearing up for its biennial Environment Assembly in February 2022, which will set its agenda for the next few years. At a preparatory meeting in February 2021, leaders agreed that the priority must be to get a shift on with tackling the three planetary emergencies simultaneously. “The three crises are climate change, nature and biodiversity loss, and waste and pollution, the toxic trail of our economic development that is essentially poisoning and toxifying the planet,” says Inger Andersen, the executive director of the UN Environment Programme (UNEP). “Unless we tackle these with real sincerity and determination, it’s a future we cannot even contemplate.”

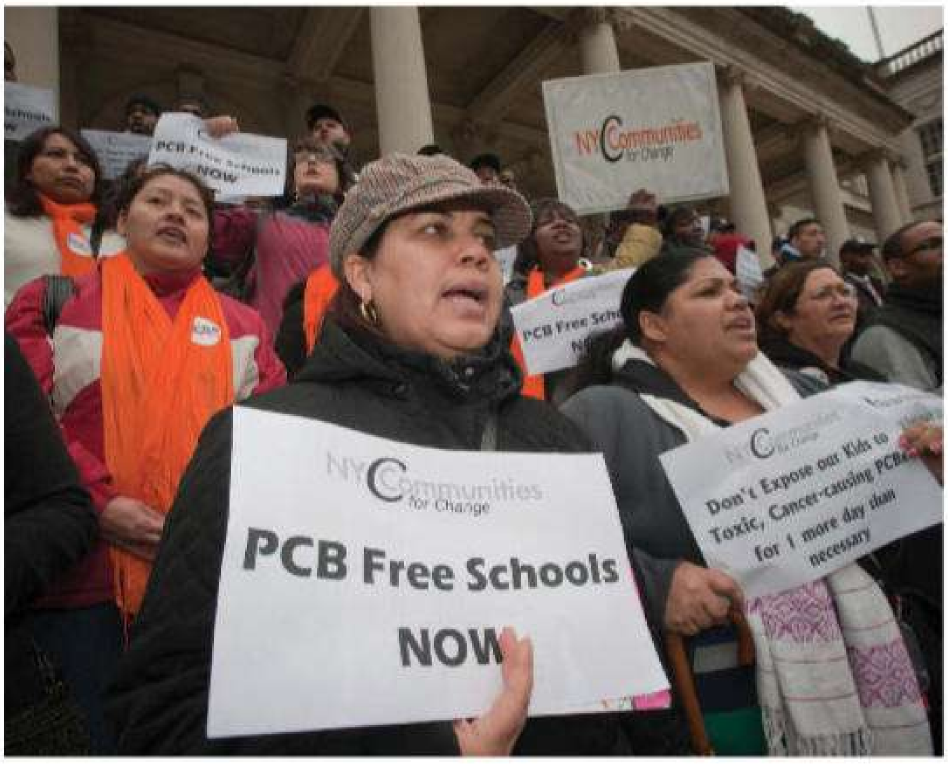
“These are interrelated crises actually, reinforcing each another,” says Ivar Baste, deputy director general of the Norwegian Ministry of Environment and a lead author of the UNEP *Making Peace with Nature* report. The connections between climate change and biodiversity loss are well established, and it is clear how chemical pollution causes both.

KNOWN NASTY

Endocrine disrupters

Defined as chemicals that interfere with hormonal signalling, endocrine-disrupting chemicals or EDCs are a broad class. They include polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) used as flame retardants, bisphenol A and phthalates, which are both mainly used to soften plastic, and perfluorooctanoic acid (PFOA). PFOA belongs to a class known as per- and polyfluoroalkyl substances (PFASs) used as surfactants and stain retardants since the 1940s. They were originally regarded as inert and safe, but some are now known to accumulate in human tissues to toxic levels.

Some endocrine disrupters, including PCBs and PFOA, also belong to a list of “persistent organic pollutants” that are known to be carcinogenic and toxic to the reproductive, nervous and immune systems.


NY Communities for Change
PCB Free Schools NOW
Don't Expose our Kids to Toxic, Cancer-causing PCBs for 1 more day than necessary
PCB Free Schools NOW

RICHARD LEVINE/ALAMY

Parents protest against the use of PCB chemicals in schools in New York in 2011

It also cuts the other way. Intact ecosystems are quite resilient against insults such as chemical pollution, says Woodward; ecosystem degradation weakens that buffer. Similarly, higher temperatures can multiply the impact of pollution. “The ways that chemicals react and degrade in the environment are typically a function of temperature,” says Ryan. “If your temperature fluctuations are now different because of climate change, then those pathways will be impacted.”

Pollution-free planet

Again, though, we simply don’t know enough. “There’s nothing really happening in that space, it’s a massive black hole,” says Woodward. “We don’t just need to know how chemicals operate in the world, we need to know how they’re going to operate in a warming world.”

The UN’s immediate goal on chemical pollution is significant progress towards a pollution-free planet by 2030. The ultimate goal might sound impossible, but that hasn’t stopped Ryan and her colleagues from setting up a project called Transition to Zero Pollution.

And zero pollution means absolute zero, she says. To get there, we need to create a circular chemical economy in which everything we use is either harmless, recyclable or manageable. She is under no illusions about how long it will take and how hard that will be. “We need a radical shift in our economic systems, our industrial systems and our business models.”

Wang says industry will push back hard, but Ryan isn’t so sure. Some of the chemical companies she works with actually want tougher rules “because without a policy change, they can’t move, because they will instantly price themselves out of the market”. The industry is also under tight public scrutiny. “I would like to say – but I’m not going to say this with 100 per cent confidence – that

›

KNOWN NASTY

Environmentally persistent pharmaceuticals

Many drugs administered to humans, pets and livestock are by design highly bioactive and resistant to breakdown, and can adversely affect wildlife once released into the environment. The veterinary anti-inflammatory drug diclofenac, for example, is poisonous to vultures that scavenge on dead livestock and has almost wiped them out on the Indian subcontinent. The most common "environmentally persistent pharmaceutical pollutants" are certain painkillers, antibiotics, lipid-lowering drugs, epilepsy drugs and oestrogens from oral contraceptives. As yet, there is no global framework to assess their risks or restrict their use.

NOEMI CASSANELLI/AFP VIA GETTY IMAGES

Chemical foam floats along the Yamuna river in New Delhi, India

given what happened with the climate crisis, they'll behave better this time. There's a drive for industry to demonstrate its environmental credentials."

New Scientist asked the ICCA if its members agreed that the pollution and waste situation is as serious as climate change and biodiversity loss, and if so, what they were doing about it. It said: "There are many challenges the world faces, including the pollution and waste situation. ICCA is committed to advancing safe, innovative, effective and economically viable chemical products and technologies that are key to unlocking sustainability solutions."

Technology is providing some new ways of combating the problem. Basic analytical techniques are improving: Barron says he can now run mixtures of thousands of chemicals through an instrument and it will identify every single one of them. Computer modelling and AI machine-learning systems, meanwhile, are allowing toxicologists to perform triage and choose to do full assays only on the chemicals that are flagged up as potentially harmful, streamlining the task of risk assessment. "We've started to use what we know already to make predictions," says Barron. Machine learning can also help to predict how mixtures of chemicals will behave once they are released into the wild, says Woodward.

So far, regulators aren't buying into machine learning in real-world risk assessments, but that may just be a matter of time as the technology matures, says Barron. Even without this, better predictions of chemicals' risk profiles provided by learning algorithms will allow us to design safer ones in future.

For chemicals already in the environment, new technology is also catalysing better waste treatment. In some of the wealthier parts of the world, the treatment of wastewater, which is where a lot of pollutants end up, has been revolutionised by bioremediation technologies that can purify contaminated water and safely dispose of the waste. "It's an amazing process how wastewater is treated now," says Barron. "It's mostly biological."

Further down the road is the concept of "essential use" – a sort of halfway house to zero – where the world somehow agrees to narrow its portfolio of synthetic chemicals to the ones we can't do without, and ideally the least harmful. We should keep in mind that not all chemicals are equally bad, says Woodward. "We need a lot of them. Most of them appear to be relatively innocuous. There are some that are clearly extremely dangerous, very toxic, and we need to understand them and identify the ones of real concern. What we have to do is balance the risk against the rewards."

Wang says that we can't delay any longer. "I hope that governments around the world can show more commitment because it is really a fundamental global threat." We have been warned. ▮

KNOWN NASTY

The rest...

The UN Environment Programme flags up a number of substances or groups of substances for which there is emerging evidence of risk, although not much in the way of detail or action. These include the neonicotinoid insecticides, the herbicide glyphosate, microplastics, organic tin compounds used as additives in plastics and pesticides, and the antibacterial agent triclosan used in many consumer products.

Graham Lawton is a feature writer for *New Scientist*

Post-human pooches

What would happen to dogs in a world without people, wonder bioethicist **Jessica Pierce** and behavioural ecologist **Marc Bekoff**

PAUL KENNEDY/ALAMY

EVEN to their biggest fans, dogs can seem ridiculously lacking in survival skills. Rufus takes off at full pelt after a squirrel with an expression of great determination, only to reach a nearby tree long after the squirrel has scampered to safety. Bella barks ferociously at a metal statue of an elk. Poppy stalks a wind-blown paper bag down the pavement. Dickens refuses to go outside to urinate because it is raining. Jethro runs home with his tail between his legs when he encounters a wild animal nearby.

Such anecdotes are a common source of amusement at dog parks, on social media and in dog-related conversations. But behind the laughter lurks an serious scientific question: if humans were to suddenly disappear from the scene, could dogs survive? After at least 14,000 years of domestication, could this species we have co-evolved with cope without provisions of food, care and regular cuddles?

Intrigued by this question, we have explored it as a thought experiment in our upcoming book, *A Dog's World*. Using evolutionary theory and the growing body of research on free-ranging dogs, we imagine a post-human future for pooches. We try to work out what they would look like; how they might forage, reproduce and raise young; the nature of their social lives; and the cognitive and emotional skills they would need to successfully navigate a world in which they must compete, cooperate and coexist with other animals. Where we wound up surprised us. Not only did it highlight the immense flexibility of our canine friends, it also revealed some important lessons about how humans can improve the lot of dogs while we are still here.

Dogs are among the most successful species of mammal on the planet. A billion or so of them inhabit every corner of the globe, living in all sorts of places, from homes and urban metropolises to deserts, rainforests and high Tibetan plateaus. When asked to imagine a dog, most people in the UK and US will picture a pet on a leash, chasing a ball in a park or gobbling a bowl of food. In fact, only a small minority of the world's dogs live as companion animals, whereas between 80 and 85 per cent live independently as feral, village, street or community dogs.

What allows dogs to thrive in such diverse ecological niches is the fact that, like all canids, they are versatile and opportunistic. They retain many of the traits and behaviours of their wild relatives, such as wolves, coyotes and jackals, with whom they can ›

Between 80 and 85 per cent of the world's billion or so dogs live independently

MALCOLM P CHAPMAN/GETTY IMAGES

still interbreed. Pet dogs may not be raised in a way that cultivates these skills. However, as a species, dogs haven't "forgotten" how to forage, hunt, procreate, raise offspring, get along in groups and defend themselves and their homes. This adaptability means that dogs are likely to survive and even flourish in a post-human world.

Nevertheless, the transition years after humans disappeared would be difficult. Meeting the demands associated with an abrupt loss of human support would require behavioural, neural, anatomical and physiological adaptations – and a healthy dose of luck. The geographical distribution of dogs would shift. Even free-ranging dogs currently tend to live in close proximity to humans but, with people out of the picture, dogs would be forced to inhabit other ecosystems. There would probably be significant die-offs during the first few years. But evolution would adapt dogs to their new life because the individuals best able to meet diverse, novel challenges would have the highest odds of surviving and passing on their genes. As a result, subsequent generations would be genetically fitter and more able to learn survival skills for themselves and from other dogs.

Compelling as the idea might be, dogs wouldn't "de-domesticate" and go back to being wolves. One way to conceptualise their possible evolutionary trajectories is through focusing on what biologists call life history strategies. The goal here is to understand how organisms evolve to balance the competing energetic costs of survival, growth and reproduction. Taking this approach with post-human dog evolution raises key questions, including which life history strategies would converge with those of other canids; how different variables, such as body size and feeding behaviour, would mesh; and how long it might take for evolutionary changes in form and behaviour to occur.

The most immediate and significant challenge faced by post-human dogs would be acquiring food. Nearly all dogs, even those that don't receive direct human support, depend to some extent on human food subsidies, which is a fancy way of saying that they eat our rubbish, waste (yes, our faeces) and handouts. Dogs are highly adaptable dietary generalists, so they could survive on a wide range of foods, from plants, berries and insects to small mammals and birds – and perhaps even some larger prey. Post-human dogs would eat whatever they could get their paws on.

"Mixing of breeds would result in dogs looking much like today's feral dogs"

Different feeding strategies would evolve over time depending on their ecological niche, local food availability and competition with other animals. Their diet would be constrained by their physical capabilities and, in turn, influence how they evolved over time. Eventually, different populations might even become distinct species, using different feeding strategies to fill a range of ecological niches.

Physical change would be rapid once human-directed artificial selection was replaced by natural selection. Humans have bred dogs to take a vast range of forms and sizes – this would change. First to go would be maladaptive traits, such as extremely foreshortened snouts, which can inhibit breathing, and pronounced skin folds, which can harbour disease-causing microbes. Within a few generations, mixing of breeds would probably result in all dogs looking very much like today's feral dogs: medium sized with pointy ears, longish snouts, straight tails and medium-length, reddish brown fur, which would be thinner or thicker depending on their habitat. However, in the longer term, populations that became isolated either geographically or due to speciation might evolve distinct physical characteristics, shaped by random genetic changes or by adaptation to a specific niche.

The mating and reproductive strategies of post-human dogs wouldn't need to shift as much as their appearance or feeding ecology. Nevertheless, there could be some changes as natural selection favoured strategies that led to greater breeding success in the absence of humans. These might include more prolonged and ritualised flirting, reverting back to coming into heat once a year as wolves do rather than twice, and greater involvement of mothers, fathers, aunts, uncles and possibly non-family members in the rearing of youngsters.

Teamwork

Many different forms of social organisation could work in a world without humans, including the formation of bonded pairs, small groups and larger packs. However, to succeed, dogs would need to sharpen their social skills, including communicating intentions and resolving conflicts. Like all social animals, dogs are capable of learning from one another, and this would be crucial for survival. Skills developed during puppies' early socialisation period would be particularly important. The inner lives of post-human dogs would also change as they evolved the cognitive skills and emotional intelligence required to interact with other animals and make them successful members of wild communities.

This may just be a thought experiment, but it can be useful to see dogs as wild animals. Considering them in this way can help us think through how to give them the best possible lives today – especially the companion dogs with whom we share our homes and that may live under surprisingly stressful conditions because they are captive and cannot fulfil their basic needs and drives without our help.

There is already incredible diversity in how dogs make their way in the world and interact with humans. Recognising this can remind us that there is no universal dog. We need to be careful not to make sweeping generalisations about what dogs do or don't do, or even what is good or bad for them: the focus needs to be on individuals. Still, looking at the behaviour of free-ranging dogs can help us identify how dogs tend to behave when left to their own devices, and so better understand and appreciate the ancient impulses that still lurk in dogs' brains, influencing what they do and how they feel. Those of us who live with pet dogs should do our best to allow and encourage them to engage in a wide range of typical and dog-appropriate behaviours. We should let them use their senses – such as their incredibly active noses – and socialise with other dogs if they enjoy it, and should also build strong bonds with them that help them develop into the emotionally and socially intelligent beings they naturally are.

It's a dog's life

Dogs co-evolved with humans and would surely face some challenges without us. However, they would also gain a lot physically, psychologically and socially if people were to suddenly disappear.

CONS:

No regular meals or access to human food sources.
Greater risk of disease, injury and predation by other animals.
No veterinary care or drugs for pain or psychological distress.
Loss of comfortable accommodation and human grooming.
Loss of human companionship and mental stimulation.

PROS:

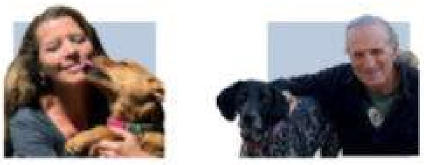
Full control over movement, reproduction and social life.
No experimentation, dog fighting, overfeeding or abuse.
No mutilation, tail docking, debarking or ear cropping.
Greater and more dog-appropriate sensory stimulation.
No selective breeding for debilitating, maladaptive traits.

JULIA LEE

Dogs are versatile and could inhabit new ecosystems without us

Our control over the breeding of pet dogs brings another responsibility. Certain traits make dogs better able to adapt to different conditions and more likely to survive and enjoy life. Others do the opposite. It is hard to think of a scenario, future or present, in which maladaptive traits are good for a dog. We should stop selectively breeding for characteristics that only serve human aesthetic desires, such as extreme size, excessive skin folds, bulging eyes and squished faces.

It isn't pleasant to imagine a world in which humans don't exist, but it is an important exercise. When we no longer put ourselves at the centre of the picture, then fruitful thinking can emerge. It helps us shine a light on who dogs are on their own terms and how our relationships with them can best benefit us both. It's a win-win. ∎



Jessica Pierce is at the University of Colorado Anschutz Medical Campus. Marc Bekoff is at the University of Colorado Boulder. Their book, *A Dog's World*, will be published in October

BEN LEWIS GILES

Where does gold come from?

Many elements are made in stars like our sun. But new evidence suggests gold's origins could be far more ancient. **Sapphire Lally** investigates

EVERYONE knows that ancient alchemists were obsessed with making gold. They never cracked it. Everyone knows that too. But here's something not a lot of people know: thousands of years later, we still don't fully understand where gold comes from. We can find it on Earth, of course. But where in the universe it was first made has long been a cosmic-scale mystery.

For most of the elements we are familiar with – carbon, oxygen, nitrogen – their origins are clear. These atoms were cooked up in the roiling hearts of stars through nuclear fusion. But bog-standard fusion is only powerful enough to produce relatively light elements. To create heavier stuff, a more powerful process is needed. The thing is, we don't know exactly how or where it happens. This applies not just to gold, but to dozens of the heavier, more exotic elements. You could say that the origins of half the elements on the periodic table are unknown.

There is no shortage of possible explanations, each of which involves the fiery deaths of stars or other celestial implosions. Now, though, we finally have some hard evidence. For the first time, we have spotted heavy elements actually being made. In exploring further, we have learned that their origins are probably far more subtle than we ever suspected.

The chemical elements are the basic building blocks of everything, including you. Along with rather a lot else, an adult body contains somewhere in the region of 16 kilograms of carbon, 780 grams of phosphorus and 0.2 milligrams of gold. Deep down, every element is made of the same three particles. There is a nucleus of positively charged protons and neutral neutrons, orbited by much smaller, negatively charged electrons. The number of protons in a nucleus determines the element: six protons means you have carbon; gold is much heavier with 79. The number of neutrons is usually the same as the number of protons, although this can vary a bit, producing slightly heavier or lighter versions of the same element, called isotopes.

Stars begin their lives as a great mass that consists almost entirely of the lightest chemical element, hydrogen, made of one proton and one electron (see "The first elements", below). Soon, the process of nuclear fusion sparks into life and hydrogen atoms merge to form helium, which has two protons. This process keeps going to produce steadily heavier elements.

But only up to a point. As atomic nuclei get bigger, the electromagnetic force begins to push them apart more strongly, and eventually they can't get close enough to fuse into heavier elements. Beyond iron, which has 26 protons, further fusion almost never happens in a star.

So where do we get the heavier elements from? In the 1950s, physicists including Fred Hoyle realised that there was an alternative to fusion. It involves neutrons, which, having no charge, are unhindered by the electromagnetic force. If an atom captures a neutron as it whizzes past, it will grow into a heavier isotope of the same element. Once inside the nucleus, a neutron can decay into a proton and an electron in a radioactive process called beta decay. This transforms the atom into an element that is one proton heavier.

Hoyle showed that there were two ways this could happen. The first is called the slow neutron-capture process (or s-process). It requires only a gentle drip of neutrons. Hoyle reckoned it could happen in dying stars called red giants, and we now have little doubt that this is true. We can look at light from red giants and spot the characteristic ways that different elements in the star absorb it – and this spectroscopic data shows that these stars do indeed contain some heavy elements. But this can't produce each and every one of the heavier elements. And anyway, the pace is glacial: a nucleus undergoing the s-process ›

The first elements

Some say we are made of stardust – and that is mostly true, as the major elements in our bodies, like carbon and oxygen, were forged inside stars. But what were the very first stars made of? It turns out that all the universe's hydrogen and most of its helium were produced in the first 20 minutes after the big bang, when things were hot and dense enough to sustain fusion. The first stars were made of just these two elements, plus a little bit of lithium (see "The missing lithium", page 48).

MILLARD H. SHARP/SCIENCE PHOTO LIBRARY

only captures a neutron about once a month. This isn't enough to explain all the heavy elements we see in the universe.

Hoyle's second mechanism is called the rapid neutron-capture process (or r-process). Here, atoms get deluged with neutrons and quickly grow to huge sizes. They then radioactively decay into a series of lighter, if still heavy, elements. We think that this must be the process responsible for making the majority of the universe's heavy elements, including gold.

But where could a big enough tidal wave of neutrons come from? Astrophysicists long believed the answer had to be a supernova, the cataclysmic explosion of a star. But in the past 20 years, there have been signs that this is wrong. For one thing, we have started using computers to simulate the r-process during a supernova, and the abundances of different elements produced in these simulations don't match real spectroscopic observations of the explosions.

Then there is a more surprising line of evidence. Earth occasionally passes through patches of dust left behind by supernovae; the dust drifts into our atmosphere and settles at the bottom of the ocean and in Antarctic ice. It is easy enough to confirm the origins of this dust because it contains a telltale isotope of iron created in supernovae. What it doesn't contain is any significant quantity of gold – a fairly convincing sign that supernovae don't produce this precious metal.

Even before such evidence emerged, back in 1974, David Schramm and James Lattimer at the University of Texas at Austin proposed that a different cosmic smash-up might be the source of gold instead. If what we need to make heavy elements is a lot of neutrons, then perhaps their origins involve neutron stars? These are incredibly dense balls of matter – mostly neutrons, as the name suggests – left behind after certain kinds of supernovae. Neutron stars often form in pairs, then spin around each other until eventually smashing together in a cataclysmic explosion called a kilonova. The tide of neutrons that results, reckoned Schramm and Lattimer, could be enough to kick-start the r-process.

In the early 2000s, Brian Metzger, now at the Flatiron Institute in New York, was taken by the idea that gold might come from kilonovae. But he was frustrated that there had been precious little thought about how we might test the idea. He began wondering how to get some hard data. "What could we actually go out and measure with a telescope?" he says.

The r-process within a kilonova would involve an absolutely massive cascade of radioactive decay, and Metzger realised that this would throw out a characteristic flare of light across the cosmos. In 2010, he predicted the intensity of light from an element-producing neutron star merger. Some colleagues at the University of California, Berkeley, developed this further to show that the flare would start off blue, as lighter elements were produced, and then shift to red, as heavier elements like gold were produced. This so-called light curve would be the smoking gun.

Cassiopeia A (right) is the remnant of a supernova that happened about 11,000 light years from Earth. We now know that gold (top) isn't made in this type of explosion

NASA/JPL-CALTECH

The search for it would prove to be tricky, to say the least. We did see likely looking flashes in the sky from time to time, but these were usually so far away that we couldn't measure the light curve with any precision. This happened in 2013, for instance, when the Hubble Space Telescope saw a burst of gamma rays thought to be caused by a kilonova. There was a promising bump of light at the end of this burst, but it was too faint to properly compare it with Metzger's predictions.

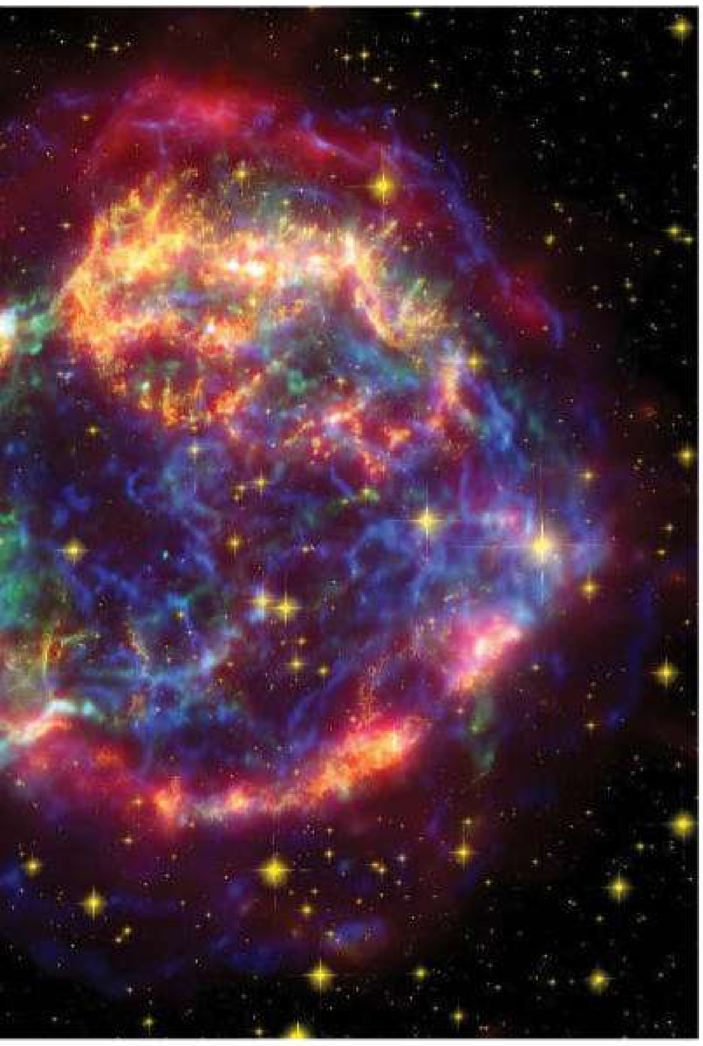
A hum and a chirp

Meanwhile, other physicists were setting up machines that could observe the universe in an entirely different way. The Laser Interferometer Gravitational-Wave Observatory, or LIGO, has detectors that can measure gravitational waves, vibrations in space-time caused by powerful cosmic collisions. In 2017, LIGO observed the clear signal of two neutron stars colliding: there was a "hum" of increasing frequency as the stars spiralled closer, then a "chirp" as they crashed together.

This was the moment Metzger had been waiting for. The gravitational waves arrived at Earth before the light from the explosion, and physicists scrambled to pinpoint the source and train optical telescopes on it, ready

The missing lithium

Our best understanding of the big bang suggests that a certain quantity of lithium should have been created then along with hydrogen and helium. From this, we can calculate how much of these elements there should be in the cosmos. Our predictions match observations for hydrogen and helium well, but about two-thirds of the lithium that should be there is missing. No one can confidently explain this long-standing niggle, known as the cosmological lithium problem. Even more strangely, certain types of stars have an inexplicably large amount of lithium. One idea is that this might come from novae, a special class of cosmic explosion not to be confused with supernovae. These can happen when a white dwarf is orbited by a much larger star. Gas from that star falls onto the white dwarf, causing an explosion that may



"For the first time ever, we have directly seen the synthesis of heavy elements"

BJÖRN WYLEZICH/ALAMY

It's raining boron

Elements number four and five, beryllium and boron, weren't produced in stars. These light elements are used up in stellar fusion reactions more quickly than they can be produced. But there is plenty of both on Earth – so what gives? It turns out that ultra-high-speed protons from space collide with nitrogen and oxygen in Earth's atmosphere, causing them to split apart into beryllium and boron. From there, the elements dissolve in water and rain down onto the surface.

to check for Metzger's blue-to-red signal. When the data came in, it looked just right. The kilonova had spat out a wave of exotic elements. "For the first time in humanity's history, we've directly seen the synthesis of these heavy elements," says Metzger.

But was there gold in that thar explosion? The most undeniable evidence would be to see the element's characteristic spectroscopic fingerprint in the light emitted from the kilonova. Unfortunately, the fingerprints of various elements overlap in the observations and it isn't possible to distinguish one from another. However, Metzger sees that as nitpicking. "When you create one of these heavy elements, it takes a lot of fine-tuning not to create a whole spectrum," he says.

Most physicists now agree that kilonovae do create gold. But that isn't the end of the story. It seems these events aren't enough to explain all of the heavy elements in the universe.

That much has become apparent from studies of certain stars in the diffuse halo that shrouds our Milky Way galaxy. These stars are thought to be exceedingly old, from an era when hardly any had died, whether in supernovae, kilonovae or any other manner. They shouldn't contain any r-process elements; if those elements are created by kilonovae, and none of those had happened before the star was born, then that star simply can't have any inside it. Strangely, however, a small group of astronomers called the R-Process Alliance that has been surveying these stars since 2018 has shown that some of them do in fact have lots of r-process elements.

This could mean something seriously weird is going on, says Terese Hansen at Texas A&M University, who is part of the alliance. If the stars are as old as we think and there is no mistake about the heavy elements, then something other than a kilonova must have created those elements.

That said, the universe was unrecognisably different at the time of the first stars. Stars grew many times bigger than they do today and they span much faster. When they reached the end of their lives, they didn't necessarily explode in a typical supernova. Some might have collapsed under their colossal gravity and shot out incredibly powerful bursts of radiation. These events, known as collapsars, were first proposed in 1993 by Stan Woosley at the University of California, Santa Cruz. "Collapsars produce these epic shock waves," says astrophysicist Emma Chapman at Imperial College London. "Within this wave, heavier elements past iron are formed because the material is compressed to levels far beyond what the star achieved in the core during its lifetime."

Maybe gold comes partly from the fiery demise of the universe's first stars, then. The idea is supported by research from Daniel Siegel at the University of Guelph in Canada. He has argued, based on the data from the 2017 kilonova and theoretical work on collapsars, that the latter are likely to be the dominant source of r-process elements. But Imre Bartos at the University of Florida and Szabolcs Márka at Columbia University, New York, have calculated that collapsars probably couldn't have provided more than about 20 per cent of r-process elements.

We now know a lot more about the origins of gold. Some of this most coveted metal was created in kilonovae and more was probably made during the deaths of the first stars. But even these two sources can't account for all the gold in the universe. It is something to ponder next time you see someone wearing gold jewellery. We still don't really know where it came from. ■

Sapphire Lally is a doctoral student at the University of Surrey, UK. She can be found on Twitter at @SapphireLally

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Citizen science

Let's count butterflies!

Over the next two weeks, the Big Butterfly Count needs help to find out the state of the UK's butterflies. **Layal Liverpool** tells you how

Layal Liverpool is digital journalist at *New Scientist*. She believes everyone can be a scientist, including you. @layallivs

What you need

The Big Butterfly Count smartphone app or website
A good spot for observation

Citizen science appears every four weeks

Next week

The science of cooking

WITH summer truly under way in the northern hemisphere, now is a perfect time to spot butterflies and day-flying moths. If you live in the UK, you can help conservation scientists by participating in this year's Big Butterfly Count.

By simply counting the amount and type of butterflies and moths you see, and logging your results via the Big Butterfly Count app or website, you can help researchers investigate where different species in the UK are located and how they are responding to climate change.

"You can't conserve something unless you know where it's found," says Zoë Randle, senior surveys officer at the UK charity behind the count, Butterfly Conservation.

This year's Big Butterfly Count started on 16 July and runs until 8 August, so there is still plenty of time to join in. Once you have chosen a place to spot butterflies and day-flying moths, wait and watch for 15 minutes and record which species you see out of 20 target species, and the highest number of individuals of that species you see at one time.

Don't worry if you don't know your painted ladies from your commas – a handy ID chart is available on the Big Butterfly Count app or website, where you can also record your observations.

Sunny weather is ideal for spotting butterflies, says Randle. "Butterflies are insects – they're cold-blooded and they need the warmth from the sun," she says.

WARCHI/GETTY IMAGES

Results from the Big Butterfly Count and other research efforts indicate that while some species are expanding their range as the planet heats up, others aren't faring as well.

"The ringlet butterfly is expanding its range due to climate change, [as are] the speckled wood and the comma," says Randle. But the small tortoiseshell butterfly, often spotted in gardens in the UK, has fallen by 79 per cent since 1976, she says.

All that information enables the charity to see what is happening, says Randle. The other great thing about the Big Butterfly Count, she says, is that many participants live in towns and cities, so people can provide data from less well studied habitats, such as local urban gardens and parks, as well as from private gardens.

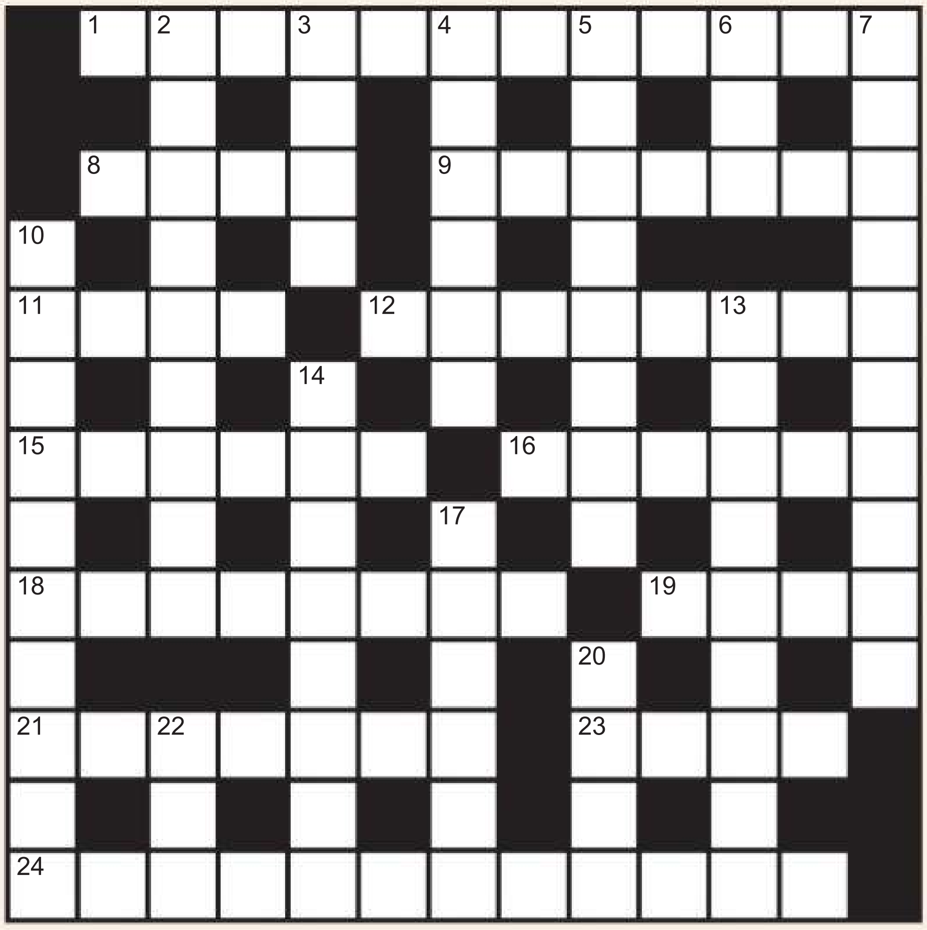
If you are a butterfly fan living in Central or North America, or in the Caribbean, you can contribute to conservation science by recording your butterfly sightings through the eButterfly project: visit e-butterfly.org to learn more.

Butterflies are an important part of food chains and contribute to ecosystems by pollinating plants, says Randle. "Everybody goes crazy about bees, but there's evidence that butterflies are good pollinators as well."

Keeping an eye on butterfly populations also provides a good indicator of how other insects are doing, including more active pollinators such as bees. "They're like a barometer of what's happening," says Randle. ▮

These articles are posted each week at newscientist.com/maker

Cryptic crossword #62 *Set by Rasa*



Scribble zone

Answers and the next quick crossword next week

ACROSS

1 Spooner's mollusc surprises birdies (12)
8 Sham electric cable getting hot instead of cold (4)
9 Tougher central London district gripped by high spirits (7)
11 Whiskeys come up in conversation (4)
12 Is oxygen issue related to deuterium and tritium, perhaps? (8)
15 Like mice carried back in souvenir umbrella (6)
16 Leaves spectacles by pine (6)
18 Exacting 24 feeding Rodents Of Unusual Size, for starters (8)
19 Traditional cosmetic found in knothole, oddly (4)
21 Pitch incorporated bit of poetry (7)
23 Edge to right of second-rate radar image (4)
24 Technician sometimes spotted fish amid ruins of Atlantis (3,9)

DOWN

2 On medication, Newton rival handcrafted decor item (6,3)
3 Approach gate after landing chopper within borders of Tripoli (4)
4 Pest setting temperature (6)
5 One way of delivering to scenic rocks (1-7)
6 Instagram celebrity initially flipping over digital enhancements (3)
7 Auctioned off parts for vehicle (German) and got rich quick (6,4)
10 Starchy alternative put back in type of soup? (10)
13 Short romp interrupting brewed drink commercial (9)
14 Phones with light-sensitive cells carrying current (8)
17 Sounds of hesitation interrupting greeting for ones up in arms? (6)
20 Touch brass instrument pointing up (4)
22 Young animal removing outer layer from diver's gear (3)

Our crosswords are now solvable online
newscientist.com/crosswords

Quick quiz #111

1 In what year were fast radio bursts first spotted?

2 Physicist César Lattes was one of several researchers credited with discovering which type of subatomic particle?

3 The largest and heaviest seeds in the world are produced by which plant?

4 In geology, what is a varve?

5 Name the chemical released by the nervous system's motor neurons in order to activate muscles.

Answers on page 55

Puzzle
set by Alison Kiddle

#123 Cara's fleet of cars

MARKO PETRUSHEVSKI/SHUTTERSTOCK

Cara is a car enthusiast. In autumn 2001, she was lucky enough to inherit a fortune from her great-aunt Mildred, and decided to create her own fleet of cars by buying a new one twice a year for the next 10 years.

UK car number plates include a two-digit number to indicate the year of registration, with two of these numbers issued each year. For example, cars registered in 2004 have 04 or 54 on the plate. The cars Cara bought in the autumn had number plates with 51, 52, 53 and so on, up to 60. The cars she bought in the spring had number plates with 02, 03, 04 and so on, up to 11.

Cara happens to love number patterns and wanted to park all her cars in a row so that in any pair of adjacent vehicles, one plate was a multiple of the other. For example, 56 could be parked next to 08 because 56 is a multiple of 8. No matter how she tried, she couldn't make a row using all the cars. What was the longest row that Cara could make?

Solution next week

"The trouble with the world is that the stupid are cocksure and the intelligent are full of doubt."
Bertrand Russell
BETTER LIVING through CHEMISTRY
SCHRÖDINGER'S CAT IS ALIVE DEAD
THE EGG CAME FIRST
LAID BY A CREATURE THAT WAS ALMOST, BUT NOT QUITE, A CHICKEN
I LIKE TO PARTY AND BY PARTY I MEAN READ BOOKS
PEOPLE'S REPUBLIC OF PANGAEA
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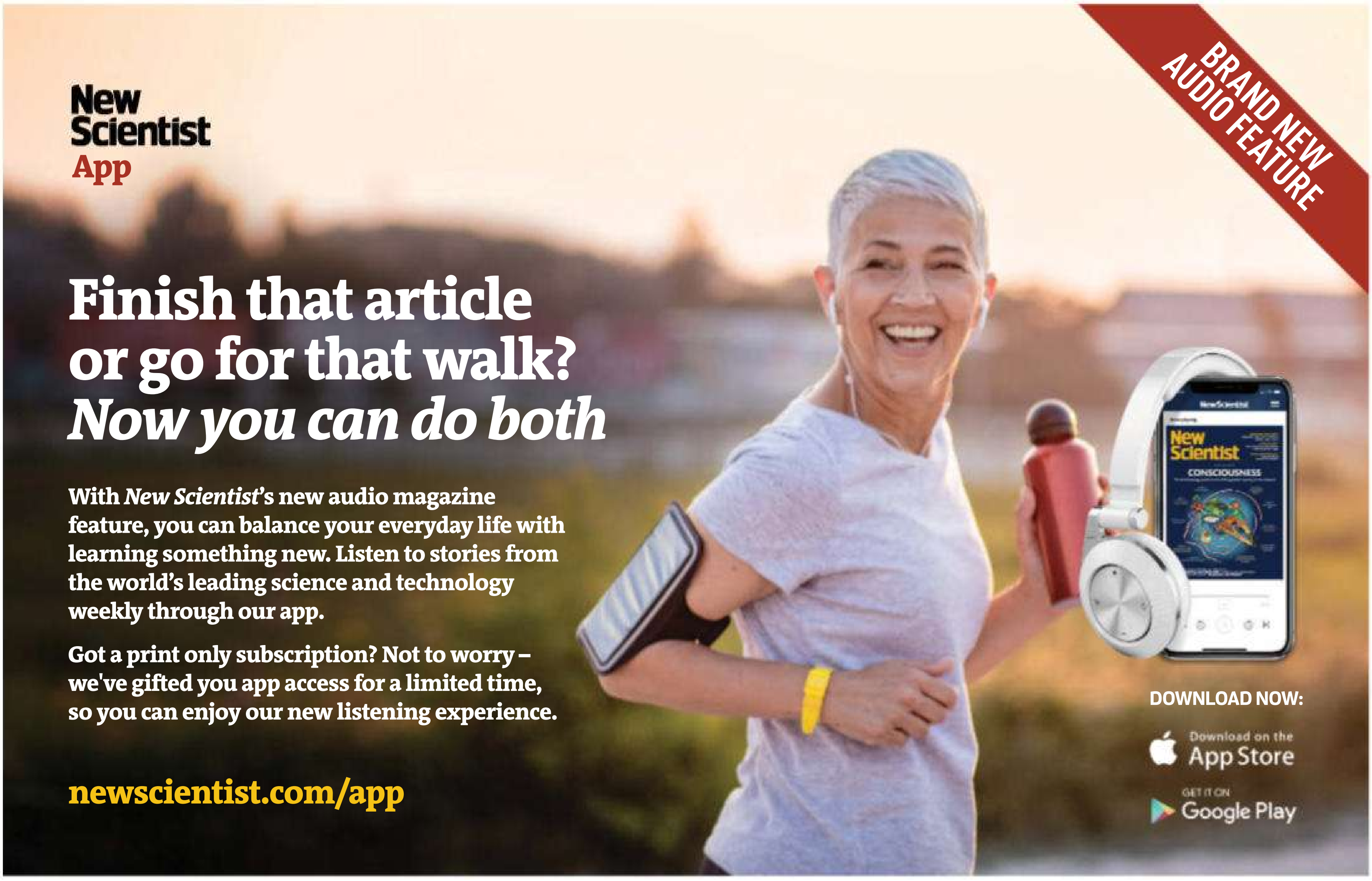

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In the dark

What would happen to Earth if the sun suddenly disappeared? How long could we live in darkness?

Peter Bursztyn
Barrie, Ontario, Canada
If the sun were to suddenly vanish, the effects would be felt immediately. Almost 50 years ago, a solar eclipse was visible in Kenya where I was working at the time – a total eclipse in the semi-desert 300 kilometres north of Nairobi.

It was a remarkable experience. Not only did we witness the grandeur of a solar eclipse in a cloudless sky, but we also saw its effects on wildlife.

A nearby zebra herd became agitated as darkness came hours early with the sun still high in the sky. The many birds flying about promptly became quiet as they settled down for the "night". During the few minutes of near-darkness, the temperature fell by 4 to 5°C.

Without sunshine, there can be no photosynthesis. Crops would stop growing. Depending on the season, we might get one last crop, or not! Our herbivores would soon chew their way through the last remaining vegetation and begin to starve. We would soon begin to starve too.

> **"Without sunshine there can be no photosynthesis. Crops would stop growing. We would soon begin to starve"**

Of course, Earth has a core of molten iron, and above that a mantle of molten rock. Some heat would filter through Earth's crust, keeping it warmish for a time. Some people could burn wood and coal for warmth, but without food we wouldn't survive long.

Dharmendra Bhatia
Indore, Madhya Pradesh, India
If the sun disappears suddenly, total darkness will be observed on Earth after 8 minutes – the time it take for its light to reach us. If darkness was the only factor, it would take a while for most life to vanish from Earth. However, there would also be a fall in temperature that would more rapidly make survival difficult.

Since the sun is the centre of gravity in our solar system, its disappearance would result in temporary anarchy among the remaining bodies, and after a few collisions the system may find a new centre. Perhaps Jupiter, or a new giant planet formed after a collision of Jupiter with other objects that orbited the sun.

If Earth were lucky enough to avoid getting caught up in these collisions and didn't just fly off into space, it might start revolving around the new centre.

David Collins
Harpenden, Hertfordshire, UK
It depends what you mean by "disappeared". If the sun was still there, but just stopped emitting light and heat, we would stay in orbit. All of Earth would be in permanent darkness; the air and oceans would retain warmth for some time, but all life would eventually freeze to death.

@Saquibclimatex
via Twitter
I am more worried about cold than darkness. Earth's surface air temperature has to be maintained in the vicinity of 15°C on average for life to survive.

Mahantesh Chikkadesai
Bagalkot, Karnataka, India
Destruction of planets would take place, because of the sudden loss of the sun's gravitational pull.

Planets, including Earth, would begin moving away from their usual paths and could collide with other gigantic bodies, leading to their destruction.

Pedro Perez
via Facebook
If the sun was no more, then Earth would be drawn to a new centre of gravity.

The gravity of Earth and the rest of the solar system would be affected and – with there being no constant energy supply from the sun – Earth would start drifting into space.

The idea that life could be sustained indefinitely without the sun is a silly dream. Maybe in some sort of base, for instance a dome with nuclear energy, humans could survive for some time.

The good thing is that there wouldn't be much life to be threatened by the nuclear waste, but there probably also wouldn't be any liquid water to cool the power system down.

If you mean just the light of the sun going, all photosynthetic organisms, including plants and algae, would die.

But if other types of energy were still coming from the sun, chemolithotrophic life would still survive, and humans could grow plants with artificial light.

We would have to adapt to living in the dark, perhaps by wearing night vision goggles.

@Sorenriise
via Twitter
Earth would continue on a linear trajectory instead of an orbit. Darkness would continue until Earth reached a new star system. When this would happen would greatly depend on the exact timing of the sun's disappearance and the particular linear course that Earth took.

PAUL HAKIMATA/AGEFOTOSTOCK/ALAMY

When did humans turn a snarl into a smile?

This week's new questions

Smile or snarl? **Grinning or baring the teeth is usually a sign of aggression in animals, so at what point did it become advantageous for humans to use this to signal friendship or mirth?** ***Veronica Haines,*** *Llanelli, Carmarthenshire, UK*

Ancient aqua **How does water become "stale"?** ***Bob Yelland,*** *Alton, Hampshire, UK*

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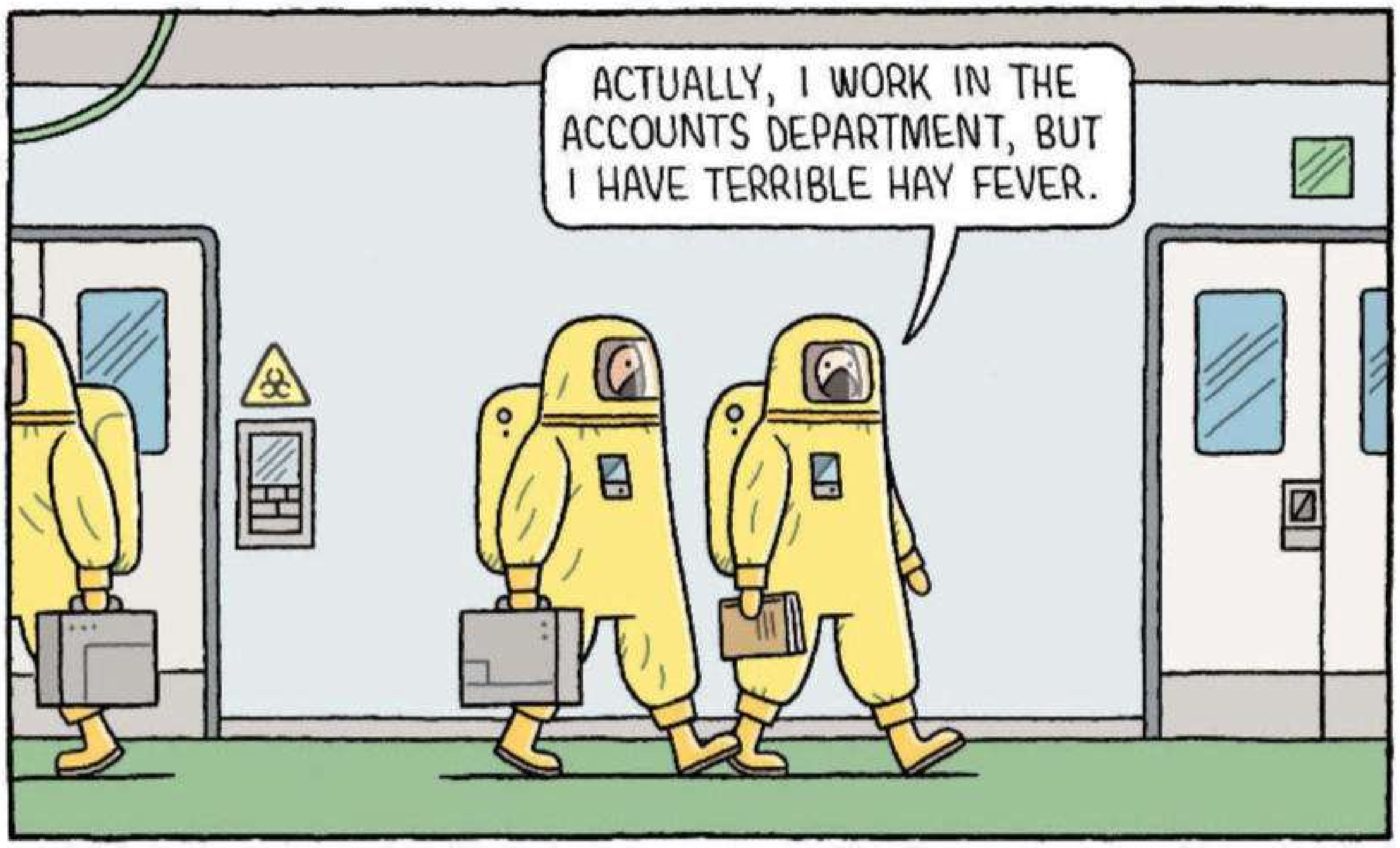
Tom Gauld
for New Scientist


ACTUALLY, I WORK IN THE ACCOUNTS DEPARTMENT, BUT I HAVE TERRIBLE HAY FEVER.

Itchy bites

What is the survival advantage to insects of their bites making us itch?

Gillian Peall
Macclesfield, Cheshire, UK
Biting insects are after our blood. To make it easier for them to imbibe it, their saliva contains an anticoagulant to stop clotting. The chemicals in their saliva enter our bloodstream, activating our immune system, which then sends a shedload of chemicals called histamines to the site in order to fight off the intruders. It is the histamines that cause the itching, hence the advice to use an anti-histamine cream.

As far as I know, and I am open to correction on this point, the brains of the insects are unable to associate a quick slurp of our blood with a delayed swipe from a human hand. They are either long gone from our skin, or their reactions are a lot quicker than ours. Those that are too slow are, of course, unable to pass on any genetic hints to their offspring.

> "The itch is a response that we have evolved to encourage us to avoid being bitten, as insects are vectors of many diseases"

Michael Price
Church Stretton, Shropshire, UK
I suggest that there is no advantage to the insect – the itch is a response that we have evolved to encourage us to avoid being bitten. This is because insects are vectors of many diseases, including malaria and yellow fever.

The bites are the way that the infection is passed on to us, and the irritation is an evolutionary reaction to the anticoagulant that insects inject into us to make it easier for them to suck our blood. The evolved itch is to remind us not to let them do it. "Once bitten, twice shy!"

Peter Meehan
London, UK
Scratching an itch may distribute insects or eggs elsewhere, or to another host, and liberate blood for neighbouring insects.

Milky microbes

Where did the bacteria that turn milk into yogurt come from? Have they evolved since humans started to store milk? If so, what did their forebears do? (continued)

Christina Sommerville
Alva, Clackmannanshire, UK
A previous reply to this question identified several bacteria which "ferment the milk sugar lactose to lactic acid, which sours milk and coagulates milk proteins".

However, I have made yogurt approximately twice a week for some time now using semi-skimmed, lactose-free milk. I use a culture from a commercial, natural bio live yogurt containing *Bifidobacteria, Lactobacillus acidophilus* and *Streptococcus thermophilus*. The end product is indistinguishable from other plain yogurt. I wonder what these bacteria are feeding on. ▮

Answers

Quick quiz #111
Answers

1 In 2007
2 A pion, or pi meson
3 The double coconut, or coco de mer (*Lodoicea maldivica*)
4 A pair of layers of sediment or sedimentary rock that is deposited annually
5 Acetylcholine

Quick Crossword #87 *Answers*

ACROSS 5 Wookie*, **7** Ptomaine, **9** Cyclamen, **10** Pineal, **11** Mouth-to-mouth, **13** Bionic, **15** Darwin, **18** Menstruation, **21** Bleach, **22** Pie chart, **23** Anemones, **24** In time

DOWN 1 Skeleton, **2** Fermat, **3** Compound, **4** Launch, **6** Oxytocin, **7** Panama, **8** Neap, **12** Kilogram, **14** Cinchona, **16** Ratchets, **17** Stapes, **18** Miasma, **19** Uremia, **20** Elon

* Apologies, we meant Wookiee

#122 Article of faith
Solution

Dan finishes on page 20. Since he halves his counting three times, the number of pages he first counts forward must be divisible by 8, call it 8k.

So overall he counts forward 8k+2k (=10k) and counts back 4k+k (=5k), and the net result is that he counts forward 5k. Call the page he starts on N. We are told that 5k+N = 4N, so 5k=3N, which means k is a multiple of 3.

And since there are fewer than 50 pages in the magazine, only k=3 works. So he starts on page 5 and counts on 24 from there, then back 12, forward 6 and back 3 to end on page 20.

Carbon carpy

Writing from a "tech bat cave in Boulder, Colorado, where all the quantum fruit loops are above average", Charles Corfield draws our attention to an advertorial in the local *Daily Camera*.

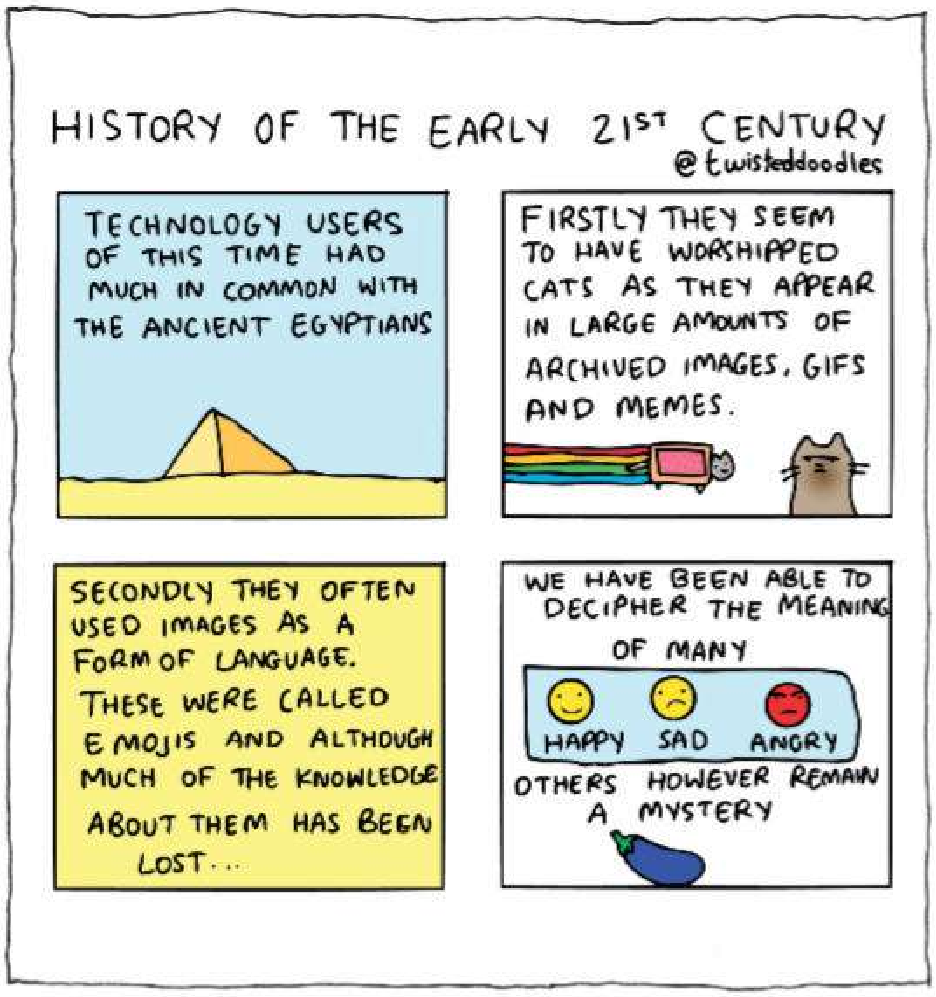
"Greska's Carbon 60: Goodbye Free Radicals, Hello Healthy Body" is the title of the puff for a product that it introduces by saying "some people call it 'electrons in a bottle'". Feedback can think of many things fitting that bill – in fact most things except ionic hydrogen or a total vacuum.

The unique human-longevity-promoting antioxidant properties of the carbon-60 "buckyballs" that it promotes are news to us, though. Following the relatively short scientific paper trail, we suspect they are mostly news to science too.

Nevertheless, we aren't one to carp, as Charles does, that "upwards of 100 billion Carbon 60 molecules per serving" might sound impressive, but is significantly less so when spread through a human body of considerably more than 100 billion times that number of molecules. Homeopathy works miracles, Charles.

We are too busy working out what other inert forms of carbon we might imbibe. We can imagine buckyballs fizz nicely on the tongue, but how about some prickly shards of graphene? Failing that, just go lick some carbon black off your car tyres, or graphite from your pencil.

Twisteddoodles *for New Scientist*


HISTORY OF THE EARLY 21ST CENTURY
@twisteddoodles
TECHNOLOGY USERS OF THIS TIME HAD MUCH IN COMMON WITH THE ANCIENT EGYPTIANS
FIRSTLY THEY SEEM TO HAVE WORSHIPPED CATS AS THEY APPEAR IN LARGE AMOUNTS OF ARCHIVED IMAGES, GIFS AND MEMES.
SECONDLY THEY OFTEN USED IMAGES AS A FORM OF LANGUAGE. THESE WERE CALLED EMOJIS AND ALTHOUGH MUCH OF THE KNOWLEDGE ABOUT THEM HAS BEEN LOST...
WE HAVE BEEN ABLE TO DECIPHER THE MEANING OF MANY
HAPPY
SAD
ANGRY
OTHERS HOWEVER REMAIN A MYSTERY

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Consideration of items sent in the post will be delayed

Dogged pursuit

News that dog owners in Tel Aviv, Israel, will soon have to register their dog's DNA with municipal authorities in an effort to cut down on dog dirt prompts one of Feedback's colleagues to reminisce that a similar scheme of testing dog DNA was trialled a few years ago in the East London suburb of Barking.

This further prompts us to recall a former letters editor of this esteemed magazine, who would occasionally refer to some of the more puzzling missives as "three stops beyond Plaistow". Feedback isn't immediately offering such a commentary on the Tel Aviv scheme. We mused on whether we risked dog-walking into a surveillance state in response to a doggy DNA testing product a couple of years ago (18 May 2019), and consider that this more than adequately marks our territory.

Mixed form

Since we are all here as fans of new science, we are indebted to Michael Zehse for pointing out, some time ago, the winning debut of the horse New Science in the 2 o'clock at Great Yarmouth, UK, on 28 May.

Sadly, at the big money Chesham Stakes at Royal Ascot on 19 June, he placed only seventh. We have been scanning the racing press ever since for further news, on the basis that three data points make a trend, but to no avail. We shall keep our ear to the ground.

What goes down...

While our thoughts are turned to the hoof and the turf, Brian Reffin Smith in Berlin writes in under the subject line "Bringing up wine".

"I am astounded that you calculated 0.01 horsepower as being the power necessary to raise the contents of a bottle of wine, but not the bottle, to the level of a cupboard door handle 1 metre off the ground in one second [3 July], without mentioning the German expression '*Er kotzt wie ein sehr kleines Pferd*', or 'He vomits like a very small horse'".

We too are astounded, Brian, for possibly different reasons. Our mental picture is now thoroughly confused, leaving us wishing we had, umm, never brought it up.

Dang and blast

Hurriedly and in passing we acknowledge a paper spotted by Steve Rothman in the August 2021 issue of the accommodatingly named journal *Structures*. It is "Structural response of simple partially-clad steel frames to long-duration blast loading" by Laura Cannon and Simon K. Clubley.

Explosive energy

Also having a blast is the *i* newspaper in the UK. In a 15 July article, sent in by Stephen Reeson, it reports that a floating solar farm in Singapore "could help to reduce carbon emissions by about 32 kilotonnes (a unit of explosive power equivalent to 1,000 tonnes of TNT) annually, comparable to taking 7,000 cars off the roads".

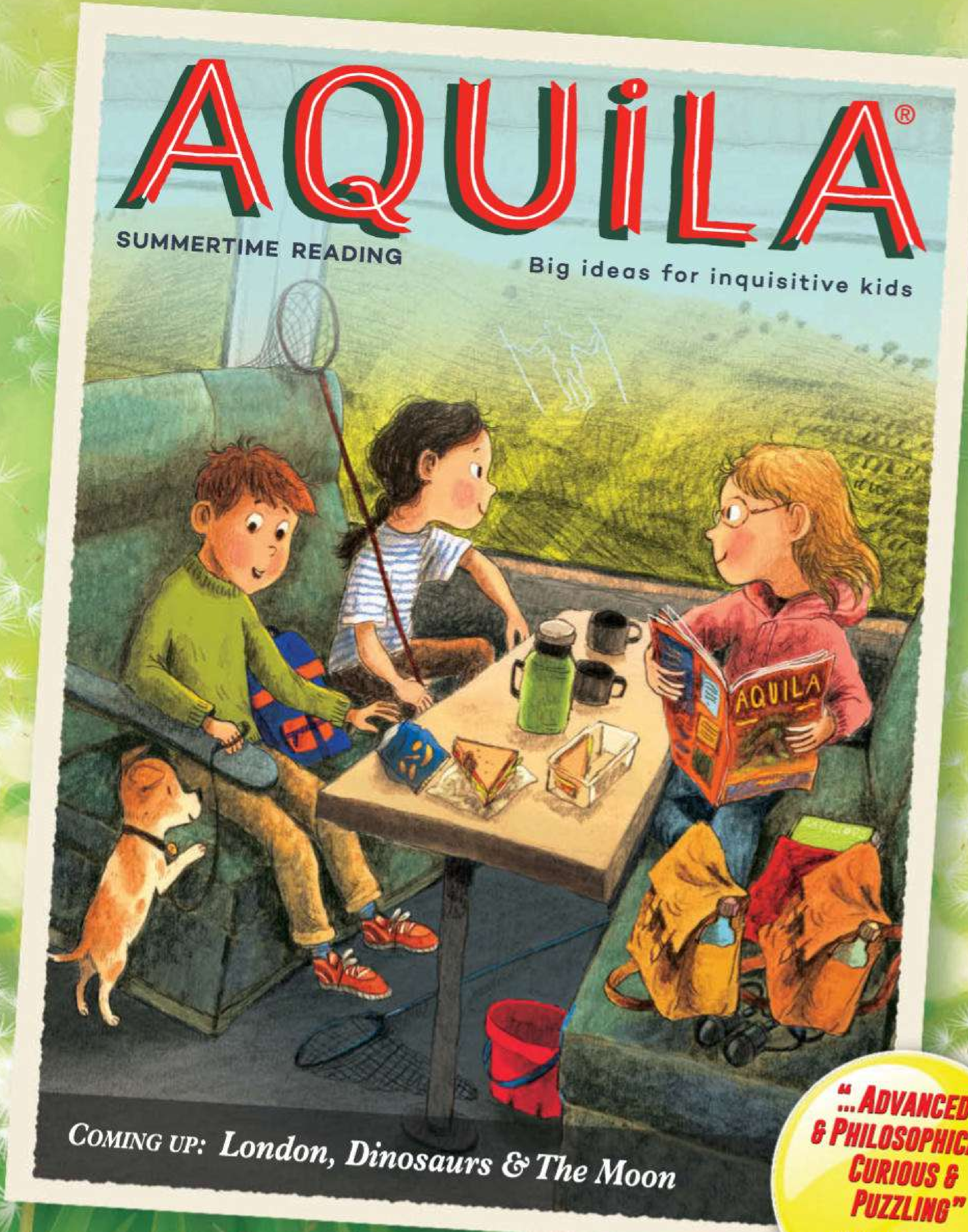
That could be enough to take 7000 cars off the roads, yes. How much would remain of the solar farm the report doesn't say.

The devil's work

At nearly a mile long, says an excerpt from the 2021 National Trust Handbook sent in by – oh, ourselves, fancy that – the Dyke Valley at the Devil's Dyke near Brighton is "the longest, deepest and widest 'dry valley' in the UK".

"Legend has it that the Devil dug this chasm to drown the parishioners of the Weald", the handbook continues. "On the other hand, scientists believe it formed naturally just over 10,000 years ago in the last ice age".

On our last visit to the Devil's Dyke, we noted that the National Trust sign for the adjoining Fulking escarpment had been subtly altered in a manner that could only have been the devil's work, but we digress. Granted, science is a belief system like any other, its main belief being that you might be wrong. Nevertheless, we get the feeling there is a false balance in the reporting here. Then again, we weren't quite around yet in the last ice age, so what do we know? ▮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